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Training Course No. 1: The Implementation of FEMWATER (ORNL-5567) Computer Program

Final Report

Prepared by G. T. Yeh

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

NUREG/CR-2705

TRAINING COURSE NO. 1: THE IMPLEMENTATION OF FEMWATER (ORNL-5567) COMPUTER PROGRAM

JUNE 1982

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Training Course No. 1: The Implementation of FEMWATER (ORNL-5567) Computer Program

Final Report

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Prepared by
G. T. Yeh

Oak Ridge National Laboratory
Oak Ridge, TN 37830

Prepared for
Division of Waste Management
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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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I

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II

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Special thanks are given to Derek A. Widmayer of the Nuclear Regulatory Commission for his many valuable suggestions in preparing this report. His efforts in converting the computer program to run on CDC equipment make a significant contribution to this report. The program is given in Appendix C.

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ABSTRACT

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This report documents a training course conducted for the U.S. Nuclear Regulatory Commission (NRC) on the implementation of a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. In addition to present basic program operation (APPENDIX A-V), the course also covered the following topics: (1) Mathematical equations and physical principles that lead to the code development (APPENDIX A-I), (2) The finite element method (APPENDIX A-II), (3) Finite-element derivation of FEMWATER (APPENDIX A-III), (4) FEMWATER program structure (APPENDIX A-IV), (5) Uniqueness and limitations of FEMWATER (APPENDIX A-VI), and (6) Running of 4 sample problems (APPENDIX B) to demonstrate various options that FEMWATER can handle. The purpose of the training seminar is to enable the NRC staff to use the model (and to be able to modify the code if necessary) for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results from other method of solution.

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INTRODUCTION

This report provides a summary and documentation of a training course conducted for the Low-Level Waste Licensing Branch of the U.S. Nuclear Regulatory Commission (NRC) by Oak Ridge National Laboratory (ORNL) on August 25-27, 1981. The course was designed to assist NRC scientists in using a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. Use of this report should be in conjunction with the FEMWATER document for assistance in using the FEMWATER code.

COURSE OBJECTIVES AND SCOPES

The main objective of the course was to present the basic operational procedure of the FEMWATER program. The ultimate purpose is to enable the NRC staff to use the code for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results with other methods of solution. To effectively achieve these objectives, a fundamental knowledge of mathematical and physical principles that form the basis of the program is required. Complete understanding of the function of all subroutines in the program is also required. Thus, in addition to basic program operation (mainly APPENDIX A-V), the course covered the following topics:

(1) Mathematical equations and physical principles that lead to the code development,

(2) Introduction to the finite element method in a simple way,

(3) Application of FEM to the governing equations,

(4) FEMWATER program structure,

(5) Uniqueness and limitations of the program, and

(6) Running of four sample problems.

COURSE MATERIALS

Materials that were distributed to the participants are included in the appendices of this report, except for the computer output of the four sample problems. The outputs of these four problems are given in the microfishe that is attached to the inside page of the back cover. Appendix A of this report includes the class notes used in the lecture presentation and some additional useful explanation. Appendix B contains complete input data of four sample problems given in the training seminar. Appendix C lists the FORTRAN source program that was converted to the CDC machine by Derek A. Widmayer of NRC.

CLASS EXERCISE

Following the course presentation, participants were given opportunities to actually code the input data for one of the sample problems. Enthusiastic discussion took place concerning the time-step size, computation of the number of time steps, interpreting soil properties from the curve to data digit, and automatic generation of data input. Interpretation of the output, which was executed on the IBM machine, was thoroughly discussed with the participants.

APPENDIX A: COURSE NOTES

A-I. FORMULATION OF GOVERNING EQUATIONS

A-II. FINITE ELEMENT METHODS (FEM)

A-III. APPLICATION OF FEM TO THE GOVERNING EQUATIONS

A-IV. FEMWATER PROGRAM STRUCTURE

A-V. FEMWATER PROGRAM REQUIREMENT AND DATA INPUT GUIDE

A-VI. UNIQUENESS AND LIMITATIONS OF FEMWATER

A-I. FORMULATION OF GOVERNING EQUATIONS

A-I.1. Introduction

The derivation of the governing equations for groundwater flow is based on the following laws:

(1) Continuity of fluid,

(2) Continuity of solid,

(3) Motion of fluid,

(4) Consolidation of the medium, and

(5) Compressibility of water.

These aspects will be discussed in the next section and followed by a discussion on specification of initial and boundary conditions.

A-I.2. Derivation of Governing Equations

1. Continuity of fluid:

$$\frac{D}{Dt}\int_{\upsilon} (S\rho_f\, n_e)\, d\upsilon = -\int_{\Gamma} \vec{n} \cdot (\rho_f\, \vec{V}_{fs})\, d\Gamma \quad . \qquad (1)$$

S = degree of saturation (dimensionless),

ρ_f = fluid density (M/L^3),

n_e = effective porosity (dimensionless),

$\vec{n}$ = outward unit vector to Γ,

$\vec{V}_{fs}$ = fluid velocity relative to solid matrix (L/T),

υ = volume of the region (L^3), and

Γ = surface enclosing the volume (L^2).

Equation (1) simply states that total rate of change of water mass within the volume υ is equal to the net mass flux through the enclosing surface Γ, which may expand or contract because of consolidation of bulk material.

Using the Reynold's transport theorem, one may rewrite Eq. (1) as

$$\int_{\upsilon} \frac{\partial(S\rho_f\, n_e)}{\partial t}\, d\upsilon + \int_{\Gamma} \vec{n} \cdot (S\rho_f\, n_e\, \vec{V}_s)\, d\Gamma + \int_{\Gamma} \vec{n} \cdot (\rho_f\, \vec{V}_{fs})\, d\Gamma = 0 \quad , \tag{2}$$

where V_s = the velocity of the surface or the solid matrix. Because υ can be arbitrary, Eq. (2) can be written in differential form as

$$\frac{\partial(S\rho_f\, n_e)}{\partial t} + \nabla \cdot (\rho_f\, n_e\, S\, \vec{V}_s) + \nabla \cdot (\rho_f\, \vec{V}_{fs}) = 0 \quad , \tag{3}$$

where ∇ is the del operator.

2. Continuity of solid:

$$\frac{D}{Dt} \int_{\upsilon} \rho_b\, (1 - n_e)\, d\upsilon = 0 \quad , \tag{4}$$

where ρ_b is the bulk density of the medium. Equation (4) states that the total amount of solid material within the material volume υ (not the spatial volume) remains constant with time. By using Reynolds transport theorem, one can rewrite Eq. (4) into the following form:

$$\int_{\upsilon} \frac{\partial(1 - n_e)}{\partial t}\, d\upsilon + \int_{\Gamma} \vec{n} \cdot [(1 - n_e)\, \vec{V}_s]\, d\Gamma = 0 \quad . \tag{5}$$

Using the Gaussian divergence theorem and the fact that υ is arbitrary, we have

$$\frac{\partial(1 - n_e)}{\partial t} + \nabla \cdot [(1 - n_e)\vec{V}_s] = 0 \quad . \tag{6}$$

3. Motion of fluid (Darcy's law):

$$\vec{V}_{fs} = -\bar{\bar{K}} \cdot \nabla H = -\bar{\bar{K}} \cdot \nabla(h + z) \quad , \tag{7}$$

$$\bar{\bar{K}} = \frac{\rho_f g}{\mu_f}\bar{\bar{k}} \quad . \tag{8}$$

H = total head (L),

h = pressure head (L),

z = potential head (L),

$\bar{\bar{K}}$ = hydraulic conductivity tensor (L/T),

$\bar{\bar{k}}$ = permeability tensor (L^2),

μ_f = viscosity of fluid ($ML^{-1}\ T^{-1}$), and

g = gravitational acceleration (L/T^2).

4. Consolidation of the medium:

$$(\lambda_s + 2\mu_s)\nabla^2 e = \nabla^2 \sigma \quad , \tag{9}$$

where λ_s and μ_s = Lame constants, e = dilatation, and σ = normal stress = ρ_f g h.

5. Compressibility of water:

$$\rho_f = \rho_f^o \, e^{\beta(p - p_o)} = \rho_f^o \, e^{\beta' h} \ , \tag{10}$$

where $\beta' = \beta \, \rho_f \, g$ = modified compressibility of water and β = compressibility of water.

Expanding the continuity equation of fluid, Eq. (3):

$$S\rho_f \frac{\partial n_e}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + n_e \rho_f \frac{\partial S}{\partial t} +$$

$$S\rho_f \, \nabla \cdot (n_e \vec{V}_s) + (n_e \vec{V}_s) \cdot \nabla (S\rho_f) + \nabla \cdot (\rho_f \vec{V}_{fs}) = 0 \ . \tag{11}$$

The first and fourth terms can be combined to yield

$$S\rho_f \frac{\partial n_e}{\partial t} + S\rho_f \, \nabla \cdot (n_e \vec{V}_s) = S\rho_f \left[\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e V_s)\right]$$

$$= S\rho_f \, \nabla \cdot \vec{V}_s \ , \text{ because of Eq. (6).} \tag{12}$$

Substitute Eq. (12) into Eq. (11):

$$n_e \, \rho_f \frac{\partial S}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + S\rho_f \, \nabla \cdot \vec{V}_s +$$

$$\cancelto{0 \ \text{second-order term}}{(n_e \vec{V}_s) \cdot (\nabla \cdot S\rho_f)} + \nabla \cdot (\rho_f \vec{V}_{fs}) = 0 \ . \tag{13}$$

Using the equation of fluid motion, Eq. (7), Eq. (13) becomes

$$n_e \rho_f \frac{\partial S}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + S\rho_f \, \nabla \cdot \vec{V}_s = \nabla \cdot [\rho_f \, \bar{\bar{K}} \cdot (\nabla h + \nabla z)] \ . \tag{14}$$

Note: up to this point, use has been made of the continuity of fluid, continuity of solid, and motion of fluid and of the assumption of neglecting second-order terms to yield Eq. (14).

Integration of the consolidation equation, Eq. (9), yields

$$(\lambda_s + 2\mu_s)e = \sigma + f \quad . \tag{15}$$

f = an integration function; it is zero if only vertical consolidation is considered. Taking the derivative of Eq. (15) with respect to time, we have

$$\frac{\partial e}{\partial t} = \frac{1}{(\lambda_s + 2\mu_s)} \frac{\partial \sigma}{\partial t} = \alpha \frac{\partial \sigma}{\partial t}, \tag{16}$$

$\alpha = \frac{1}{(\lambda_s + 2\mu_s)}$ = compressibility of consolidation.

By definition:

$$e = \nabla \cdot \vec{U} \quad , \quad \vec{V}_s = \frac{\partial \vec{U}}{\partial t} \quad , \tag{17}$$

$\vec{U}$ = displacement vector.

Hence

$$\nabla \cdot \vec{V}_s = \frac{\partial(\nabla \cdot \vec{U})}{\partial t} = \frac{\partial e}{\partial t} = \alpha \frac{\partial \sigma}{\partial t} = \alpha \rho_f g \frac{\partial h}{\partial t} = \alpha' \frac{\partial h}{\partial t} \quad , \tag{18}$$

α' = modified compressibility of medium (= $\alpha \rho_f g$).

The moisture content, θ, is by definition given as

$$\theta = n_e S \quad . \tag{19}$$

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The specific moisture capacity is defined as

$$\frac{d\theta}{dh} = n_e \frac{\partial S}{\partial h} \tag{20}$$

from which

$$\frac{d\theta}{dh}\frac{\partial h}{\partial t} = n_e \frac{\partial S}{\partial t} \quad . \tag{21}$$

From the equation of state for compressibility of water, Eq. (10), we have

$$\frac{\partial \rho_f}{\partial t} = \rho_f \beta' \frac{\partial h}{\partial t} \quad . \tag{22}$$

Substituting Eqs. (18), (19), (21), and (22) into Eq. (14), we have the governing equations, after neglecting the second-order term, $[K \cdot (\nabla h + \nabla z)] \cdot \nabla \rho_f$:

$$F \frac{\partial h}{\partial t} = \nabla \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] \quad , \tag{23}$$

$$F = \frac{\theta}{n_e} \alpha' + \theta \beta' \frac{d\theta}{dh} \quad . \tag{24}$$

A-I.3. Specification of Initial and Boundary Conditions

* Dynamic point of view -- A boundary segment can be impervious or flow-through;

* Physical point of view -- A boundary segment can be a soil-soil interface, air-soil interface, or soil-water interface;

- * Mathematical point of view -- A boundary segment can be a Dirichlet (prescribed head), a Neumann (prescribed derivative flux), a Cauchy (prescribed total flux), or a Variable (either Dirichlet or Cauchy).

These complex interrelationships are shown in Fig. A-1.

In summary:

Initial Conditions -

$$h = h_o\ (x,z) \text{ in } R \quad ; \tag{25}$$

Boundary Conditions -

$$h = h_1 \text{ on } B_1 \text{ (Dirichlet)} \quad , \tag{26}$$

$$- \vec{n} \cdot [\bar{\bar{K}} \cdot \nabla h] = q_2 \text{ on } B_2 \text{ (Neumann)} \quad , \tag{27}$$

$$- \vec{n} \cdot [\bar{\bar{K}} \cdot \nabla h + \bar{\bar{K}} \cdot \nabla z] = q_3 \text{ on } B_3 \text{ (Cauchy)} \quad , \tag{28}$$

$$h = h_4\ (x,z,t) \text{ on } B_4 \tag{29a}$$

or (Variable)

$$- \vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z] = q_4 \text{ on } B_4 \quad . \tag{29b}$$

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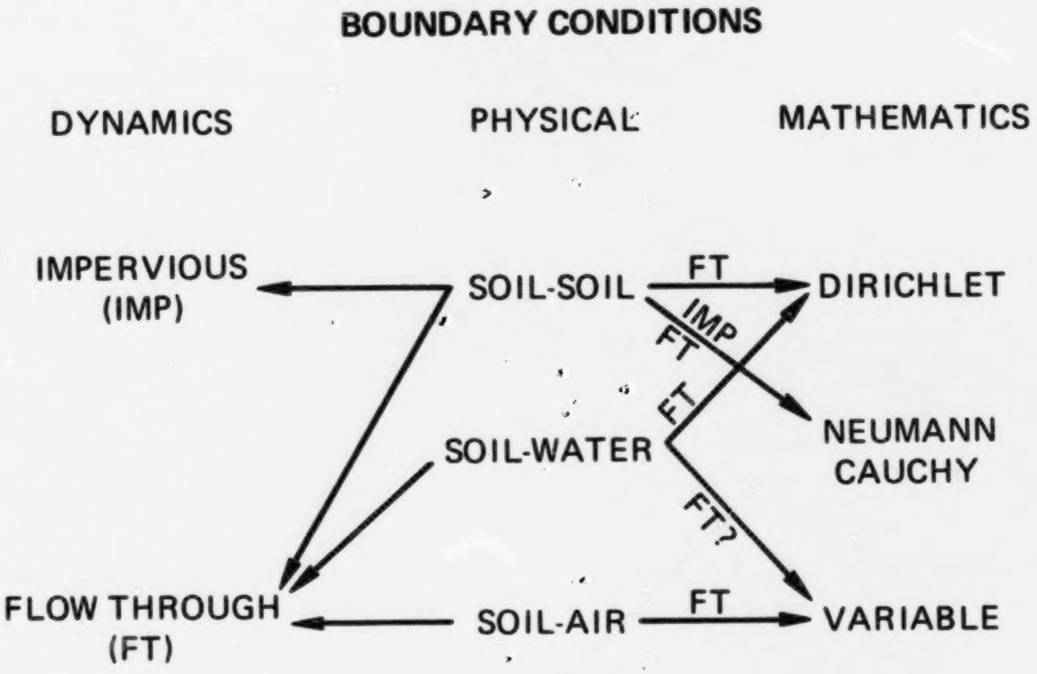

BOUNDARY CONDITIONS
DYNAMICS
PHYSICAL
MATHEMATICS
IMPERVIOUS (IMP)
SOIL-SOIL
FT
DIRICHLET
IMP
FT
FT
SOIL-WATER
NEUMANN CAUCHY
FT?
FLOW THROUGH (FT)
SOIL-AIR
FT
VARIABLE

Fig. A-1. Boundary conditions from physical point of view, dynamic point of view, and mathematical point of view.

A-II. FINITE ELEMENT METHODS

A-II.1. Introduction

The following are the steps of applying the finite element method (FEM) to differential equations:

(1) Divide the region into elements and nodes,

(2) Define base functions for each node,

(3) Define weighting functions for each node,

(4) Approximate the function in terms of base functions and node values,

(5) Define the residual as the difference between true solution and approximate solution,

(6) Set weighted residual to zero,

(7) Derive the matrix equation,

(8) Incorporate boundary conditions to the matrix equation, and

(9) Use initial conditions to advance the solution through time.

A-II.2. A Simple Example

The steps of applying FEM to differential equations are best explained by showing how they are applied to a simple example. The governing equation of the simple example is

$$\frac{\partial f}{\partial t} - \frac{\partial^2 f}{\partial x^2} = 0 \quad . \tag{1}$$

The initial condition is

$$f = 0 \quad \text{at} \quad t = 0 \quad . \tag{2}$$

The boundary conditions are

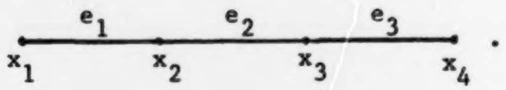
$$f = 1 \quad \text{at} \quad x = x_1 \tag{3}$$

and

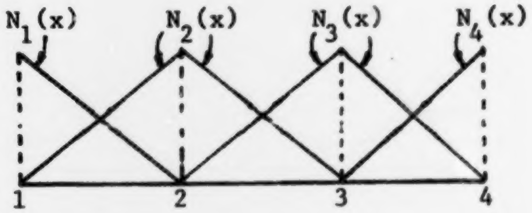
$$\frac{\partial f}{\partial x} = f \quad \text{at} \quad x = x_4 \quad . \tag{4}$$

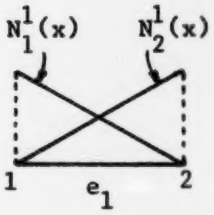
Solution Procedure

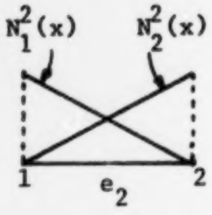
Step 1 - Divide region into 3 elements and four nodes:

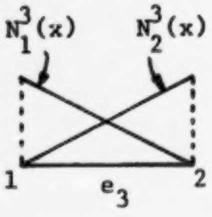

e_1
e_2
e_3
x_1
x_2
x_3
x_4

Step 2 - Define base functions both globally and locally:


$N_1(x)$
$N_2(x)$
$N_3(x)$
$N_4(x)$
1
2
3
4


$N_1^1(x)$
$N_2^1(x)$
1
e_1
2


$N_1^2(x)$
$N_2^2(x)$
1
e_2
2


$N_1^3(x)$
$N_2^3(x)$
1
e_3
2

$N_1(x)$, $N_2(x)$, $N_3(x)$, $N_4(x)$ = base functions for nodes 1, 2, 3, and 4, respectively;

$N_1^1(x)$, $N_2^1(x)$ = the first- and second-node base function for element e_1;

$N_1^2(x)$, $N_2^2(x)$ = the first- and second-node base function for element e_2;

$N_1^3(x)$, $N_2^3(x)$ = the first- and second-node base function for element e_3.

It is seen that

* Over element e_1

$$N_1^1(x) = N_1(x),\ N_2^1(x) = N_2(x) \quad .$$

* Over element e_2

$$N_1^2(x) = N_2(x),\ N_2^2(x) = N_3(x) \quad .$$

* Over element e_3

$$N_1^3(x) = N_3(x),\ N_2^3(x) = N_4(x) \quad .$$

Step 3 - Define weighting functions:

$$\left.\begin{aligned} W_1(x) &= N_1(x) \\ W_2(x) &= N_2(x) \\ W_3(x) &= N_3(x) \\ W_4(x) &= N_4(x) \end{aligned}\right\} \quad \text{Galerkin Weighting} \qquad (5)$$

Step 4 - Approximate the solution by linear combination of base functions:

$$f \simeq \hat{f} = f_1(x)\, N_1(x) + f_2(x)\, N_2(x) + f_3(x)\, N_3(x) + f_4(x)\, N_4(x)$$

$$= \sum_{j=1}^{4} f_j(x)\, N_j(x) \quad . \qquad (6)$$

Step 5 - Define residual:

$$R = \frac{\partial \hat{f}}{\partial t} - \frac{\partial^2 \hat{f}}{\partial x^2} \quad . \qquad (7)$$

Step 6 - Set weighted residuals to zero:

$$\int_{x_1}^{x_4} W_i(x) \left\{ \frac{\partial \hat{f}}{\partial t} - \frac{\partial^2 \hat{f}}{\partial x^2} \right\} dx = 0 \quad , \qquad (8)$$

$$i = 1, 2, 3, 4 \quad .$$

Step 7 - Derive matrix equation:

$$\int_{x_1}^{x_4} W_i(x) \frac{\partial \hat{f}}{\partial t}\, dx + \int_{x_1}^{x_4} \frac{dW_i(x)}{dx} \cdot \frac{\partial \hat{f}}{\partial x}\, dx = W_i(x) \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} \quad , \qquad (9)$$

$$\underbrace{\left(\int_{x_1}^{x_4} W_i\, N_j\, dx \right)}_{a_{ij}} \frac{df_j}{dt} + \underbrace{\left(\int_{x_1}^{x_4} \frac{dW_i}{dx} \frac{dN_j}{dx}\, dx \right)}_{b_{ij}} f_j = B_i \quad , \qquad (10)$$

$$B_i = W_i(x) \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} \qquad i = 1, 2, 3, 4 \quad , \qquad (10a)$$

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$$[a]\left\{\frac{df}{dt}\right\} + [b]\left\{f\right\} = \left\{B\right\} \quad , \qquad (11)$$

where [a] = mass matrix, [b] = stiff matrix, and $\{B\}$ = boundary load vector,

$$a_{11}\frac{df_1}{dt} + a_{12}\frac{df_2}{dt} + a_{13}\frac{df_3}{dt} + a_{14}\frac{df_4}{dt} + b_{11}f_1 + b_{12}f_2 + b_{13}f_3 + b_{14}f_4 = B_1 \quad , \qquad (12)$$

$$a_{21}\frac{df_1}{dt} + a_{22}\frac{df_2}{dt} + a_{23}\frac{df_3}{dt} + a_{24}\frac{df_4}{dt} + b_{21}f_1 + b_{22}f_2 + b_{23}f_3 + b_{24}f_4 = B_2 \quad , \qquad (13)$$

$$a_{31}\frac{df_1}{dt} + a_{32}\frac{df_2}{dt} + a_{33}\frac{df_3}{dt} + a_{34}\frac{df_4}{dt} + b_{31}f_1 + b_{32}f_2 + b_{33}f_3 + b_{34}f_4 = B_3 \quad , \qquad (14)$$

$$a_{41}\frac{df_1}{dt} + a_{42}\frac{df_2}{dt} + a_{43}\frac{df_3}{dt} + a_{44}\frac{df_4}{dt} + b_{41}f_1 + b_{42}f_2 + b_{43}f_3 + b_{44}f_4 = B_4 \quad , \qquad (15)$$

$$a_{11} = \int_{x_1}^{x_4} N_1N_1\,dx = \int_{x_1}^{x_2} N_1N_2\,dx + \int_{x_2}^{x_3} N_1N_2\,dx + \int_{x_3}^{x_4} N_1N_2\,dx$$

$$= \underbrace{\int_{e_1} N_1^1N_1^1\,dx}_{a_{11}^1} + \int_{e_2} 0 \cdot 0\,dx + \int_{e_3} 0 \cdot 0\,dx \quad , \qquad (16)$$

$$a_{12} = \int_{x_1}^{x_4} N_1N_2\,dx = \int_{x_1}^{x_2} N_1N_2\,dx + \int_{x_2}^{x_3} N_1N_2\,dx + \int_{x_3}^{x_4} N_1N_2\,dx$$

$$= \underbrace{\int_{e_1} N_1^1N_1^1\,dx}_{a_{12}^1} + \int_{e_2} 0 \cdot N_1^2\,dx + \int_{e_3} 0 \cdot 0\,dx \quad , \qquad (17)$$

$$a_{13} = \int_{x_1}^{x_4} N_1N_3\,dx = \int_{x_1}^{x_2} N_1N_3\,dx + \int_{x_2}^{x_3} N_1N_3\,dx + \int_{x_3}^{x_4} N_1N_3\,dx$$

$$= \int_{e_1} N_1^1 \cdot 0\,dx + \int_{e_2} 0 \cdot N_2^2\,dx + \int_{e_3} 0 \cdot N_1^3\,dx \quad , \tag{18}$$

$$a_{14} = \int_{x_1}^{x_4} N_1N_4\,dx = \int_{x_1}^{x_2} N_1N_4\,dx + \int_{x_2}^{x_3} N_1N_4\,dx + \int_{x_3}^{x_4} N_1N_4\,dx$$

$$= \int_{e_1} N_1^1 \cdot 0\,dx + \int_{e_2} 0 \cdot 0\,dx + \int_{e_3} 0 \cdot N_2^3\,dx \quad , \tag{19}$$

$$a_{21} = \int_{x_1}^{x_4} N_2N_1\,dx = \int_{x_1}^{x_2} N_2N_1\,dx + \int_{x_2}^{x_3} N_2N_1\,dx + \int_{x_3}^{x_4} N_2N_1\,dx$$

$$= \underbrace{\int_{e_1} N_2^1N_1^1\,dx}_{a_{21}^1} + \int_{e_2} N_1^2 \cdot 0dx + \int_{e_3} 0 \cdot 0\,dx \quad , \tag{20}$$

$$a_{22} = \int_{x_1}^{x_4} N_2N_2\,dx = \int_{x_1}^{x_2} N_2N_2\,dx + \int_{x_2}^{x_3} N_2N_2\,dx + \int_{x_3}^{x_4} N_2N_2\,dx$$

$$= \underbrace{\int_{e_1} N_2^1N_2^1\,dx}_{a_{22}^1} + \underbrace{\int_{e_2} N_1^2N_1^2\,dx}_{a_{11}^2} + \int_{e_3} 0 \cdot 0\,dx \quad , \tag{21}$$

$$a_{23} = \int_{x_1}^{x_4} N_2N_3\,dx = \int_{x_1}^{x_2} N_2N_3\,dx + \int_{x_2}^{x_3} N_2N_3\,dx + \int_{x_3}^{x_4} N_2N_3\,dx$$

$$= \int_{e_1} N_2^1 \cdot 0\,dx + \underbrace{\int_{e_2} N_1^2N_2^2\,dx}_{a_{12}^2} + \int_{e_3} 0 \cdot N_1^3\,dx \quad , \tag{22}$$

$$a_{24} = \int_{x_1}^{x_4} N_2N_4 \; dx = \int_{x_1}^{x_2} N_2N_4 \; dx + \int_{x_2}^{x_3} N_2N_4 \; dx + \int_{x_3}^{x_4} N_2N_4 \; dx$$

$$= \int_{e_1} N_2^1 \cdot 0 \; dx + \int_{e_2} N_1^2 \cdot 0 \; dx + \int_{e_3} 0 \cdot N_2^3 \; dx \quad , \qquad (23)$$

$$a_{31} = \int_{x_1}^{x_4} N_3N_1 \; dx = \int_{x_1}^{x_2} N_3N_1 \; dx + \int_{x_2}^{x_3} N_3N_1 \; dx + \int_{x_3}^{x_4} N_3N_1 \; dx$$

$$= \int_{e_1} 0 \cdot N_1^1 \; dx + \int_{e_2} N_2^2 \cdot 0 \; dx + \int_{e_3} N_1^3 \cdot 0 \; dx \quad , \qquad (24)$$

$$a_{32} = \int_{x_1}^{x_4} N_3N_2 \; dx = \int_{x_1}^{x_2} N_3N_2 \; dx + \int_{x_2}^{x_3} N_3N_2 \; dx + \int_{x_3}^{x_4} N_3N_2 \; dx$$

$$= \int_{e_1} 0 \cdot N_2^1 \; dx + \underbrace{\int_{e_2} N_2^2 \, N_1^2 \; dx}_{a_{21}^2} + \int_{e_3} N_1^3 \cdot 0 \; dx \quad , \qquad (25)$$

$$a_{33} = \int_{x_1}^{x_4} N_3N_3 \; dx = \int_{x_1}^{x_2} N_3N_3 \; dx + \int_{x_2}^{x_3} N_3N_3 \; dx + \int_{x_3}^{x_4} N_3N_3 \; dx$$

$$= \int_{e_1} 0 \cdot 0 \; dx + \underbrace{\int_{e_2} N_2^2 \, N_2^2 \; dx}_{a_{21}^2} + \underbrace{\int_{e_3} N_1^3 \, N_1^3 \; dx}_{a_{11}^3} \quad , \qquad (26)$$

$$a_{34} = \int_{x_1}^{x_4} N_3N_4 \; dx = \int_{x_1}^{x_2} N_3N_4 \; dx + \int_{x_2}^{x_3} N_3N_4 \; dx + \int_{x_3}^{x_4} N_3N_4 \; dx$$

$$= \int_{e_1} 0 \cdot 0 \; dx + \int_{e_2} N_2^2 \cdot 0 \; dx + \underbrace{\int_{e_3} N_1^3 \, N_2^3 \; dx}_{a_{12}^3} \quad , \qquad (27)$$

$$a_{41} = \int_{x_1}^{x_4} N_4N_1\ dx = \int_{x_1}^{x_2} N_4N_1\ dx + \int_{x_2}^{x_3} N_4N_1\ dx + \int_{x_3}^{x_4} N_4N_1\ dx$$

$$= \int_{e_1} 0 \cdot N_1^1\ dx + \int_{e_2} 0 \cdot 0\ dx + \int_{e_3} N_2^3 \cdot 0\ dx \quad , \tag{28}$$

$$a_{42} = \int_{x_1}^{x_4} N_4N_2\ dx = \int_{x_1}^{x_2} N_4N_2\ dx + \int_{x_2}^{x_3} N_4N_2\ dx + \int_{x_3}^{x_4} N_4N_2\ dx$$

$$= \int_{e_1} 0 \cdot N_2^1\ dx + \int_{e_2} 0 \cdot N_1^2\ dx + \int_{e_3} N_2^2 \cdot 0\ dx \quad , \tag{29}$$

$$a_{43} = \int_{x_1}^{x_4} N_4N_3\ dx = \int_{x_1}^{x_2} N_4N_3\ dx + \int_{x_2}^{x_3} N_4N_3\ dx + \int_{x_3}^{x_4} N_4N_3\ dx$$

$$= \int_{e_1} 0 \cdot 0\ dx + \int_{e_2} 0 \cdot N_2^2\ dx + \underbrace{\int_{e_3} N_2^3\ N_1^3\ dx}_{a_{22}^3} \quad , \tag{30}$$

$$a_{44} = \int_{x_1}^{x_4} N_4N_4\ dx = \int_{x_1}^{x_2} N_4N_4\ dx + \int_{x_2}^{x_3} N_4N_4\ dx + \int_{x_3}^{x_4} N_4N_4\ dx$$

$$= \int_{e_1} 0 \cdot 0\ dx + \int_{e_2} 0 \cdot 0\ dx + \underbrace{\int_{e_3} N_2^3\ N_2^3\ dx}_{a_{22}^3} \quad , \tag{31}$$

$$[a] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad , \tag{32}$$

$$[a] = \left[\begin{array}{c|c|c|c} a_{11}^{1} & a_{12}^{1} & 0 & 0 \\ \hline a_{21}^{1} & a_{22}^{1} + a_{11}^{2} & a_{12}^{2} & 0 \\ \hline 0 & a_{21}^{2} & a_{22}^{2} + a_{11}^{3} & a_{12}^{3} \\ \hline 0 & 0 & a_{21}^{3} & a_{22}^{3} \end{array}\right] , \qquad (33)$$

Similarily,

$$[b] = \left[\begin{array}{c|c|c|c} b_{11}^{1} & b_{12}^{1} & 0 & 0 \\ \hline b_{21}^{1} & b_{22}^{1} + b_{11}^{2} & b_{12}^{2} & 0 \\ \hline 0 & b_{21}^{2} & b_{22}^{2} + b_{11}^{3} & b_{12}^{3} \\ \hline 0 & 0 & b_{21}^{3} & b_{22}^{3} \end{array}\right] , \qquad (34)$$

$$B_1 = W_1 \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_1 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_4} - N_1 \frac{dN_j}{dx} f_j \Bigg|_{x=x_1} = \triangle \ , \qquad (35)$$

$$B_2 = W_2 \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_2 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_4} - \cancelto{0}{N_2 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_1} = 0 \ , \qquad (36)$$

$$B_3 = W_3 \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_3 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_4} - \cancelto{0}{N_3 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_1} = 0 \ , \qquad (37)$$

$$B_4 = W_4 \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} = N_4 \ f_j \Bigg|_{x=x_4} - \cancelto{0}{N_4 \frac{dN_j}{dx}} f_j \Bigg|_{x=x_1} = f_4 \ , \qquad (38)$$

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Thus,

$$\{B\} = \begin{Bmatrix} \blacktriangle \\ 0 \\ 0 \\ f_4 \end{Bmatrix}, \tag{39}$$

$$\begin{bmatrix} a_{11} & a_{12} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \begin{Bmatrix} \frac{df_1}{dt} \\ \frac{df_2}{dt} \\ \frac{df_3}{dt} \\ \frac{df_4}{dt} \end{Bmatrix} + \begin{bmatrix} b_{11} & b_{12} & 0 & 0 \\ b_{21} & b_{22} & b_{23} & 0 \\ 0 & b_{32} & b_{33} & b_{34} \\ 0 & 0 & b_{43} & b_{44} \end{bmatrix} \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{Bmatrix} = \begin{Bmatrix} \blacktriangle \\ 0 \\ 0 \\ f_4 \end{Bmatrix}. \tag{40}$$

Step 8 - Incorporate boundary conditions into the matrix equation:

$$a_{11} = 0,\ a_{12} = 0,\ b_{11} = 1,\ b_{12} = 0 \tag{41a}$$

and

$$\blacktriangle = 1 \quad . \tag{41b}$$

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The final matrix equation is

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \left\{ \begin{matrix} df_1/dt \\ df_2/dt \\ df_3/dt \\ df_4/dt \end{matrix} \right\} + \begin{bmatrix} 1 & 0 & 0 & 0 \\ b_{21} & b_{22} & b_{23} & 0 \\ 0 & b_{32} & b_{33} & b_{34} \\ 0 & 0 & b_{43} & b_{44}-1 \end{bmatrix} \left\{ \begin{matrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{matrix} \right\} = \left\{ \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \end{matrix} \right\}. \qquad (42)$$

Step 9 - Solve the initial value problem, Eq. (42). Matrix equation, Eq. (42), can be solved by any of the six numerical schemes as reported in FEMWATER - ORNL-5567.

A-III. APPLICATION OF FEM TO GOVERNING EQUATION

The application of FEM to the problem of flow-through saturated-unsaturated porous media is straight foward as that presented in Section A-II for the simple example.

The governing equation is

$$F \frac{\partial h}{\partial t} = \nabla \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] \quad . \tag{1}$$

The initial conditions is

$$h = h_I \quad . \tag{2}$$

The boundary conditions are

$$h = h_D \quad \text{on the Dirichlet Boundary} \quad , \tag{3}$$

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] = q_N \quad \text{on the Neumann Boundary} \quad , \tag{4}$$

$$h = h_V \quad \text{or} \tag{5a}$$

$$\text{on the Variable Boundary} \quad .$$

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] = q_V \tag{5b}$$

Equations (1) through (5) have mathematically defined the problem at hand. We may now proceed to apply the FEM to the governing equation and the boundary conditions following the same procedures as those in Section A-II.

Solution Procedure

Step 1 - Divide the region of interest into N nodes and M elements. Each node is specified by its spatial coordinate.

Step 2 - Define base functions both over the region of interest and over each element. Let N_j be the base function of node j. We will use a bilinear base function; i.e., N_j will have the value of 1.0 at the nodal point j and the values of 0.0 at all other nodal points, f, g, h, i, k, l, m, and n (Fig. A-2). Furthermore, N_j will vary bilinearly over those elements that have one nodal point coinciding with j and will have the value of 0.0 over all other elements (Fig. A-2). It is seen that

over element a,

$$N_1^a = N_f,\ N_2^a = N_i,\ N_3^a = N_j,\ N_4^a = N_g \quad ; \tag{6a}$$

over element b,

$$N_1^b = N_g,\ N_2^b = N_j,\ N_3^b = N_k,\ N_4^b = N_h \quad ; \tag{6b}$$

over element c,

$$N_1^c = N_i,\ N_2^c = N_l,\ N_3^c = N_m,\ N_4^c = N_j \quad ; \tag{6c}$$

over element d,

$$N_1^d = N_j,\ N_2^d = N_m,\ N_3^d = N_n,\ N_4^d = N_k \quad , \tag{6d}$$

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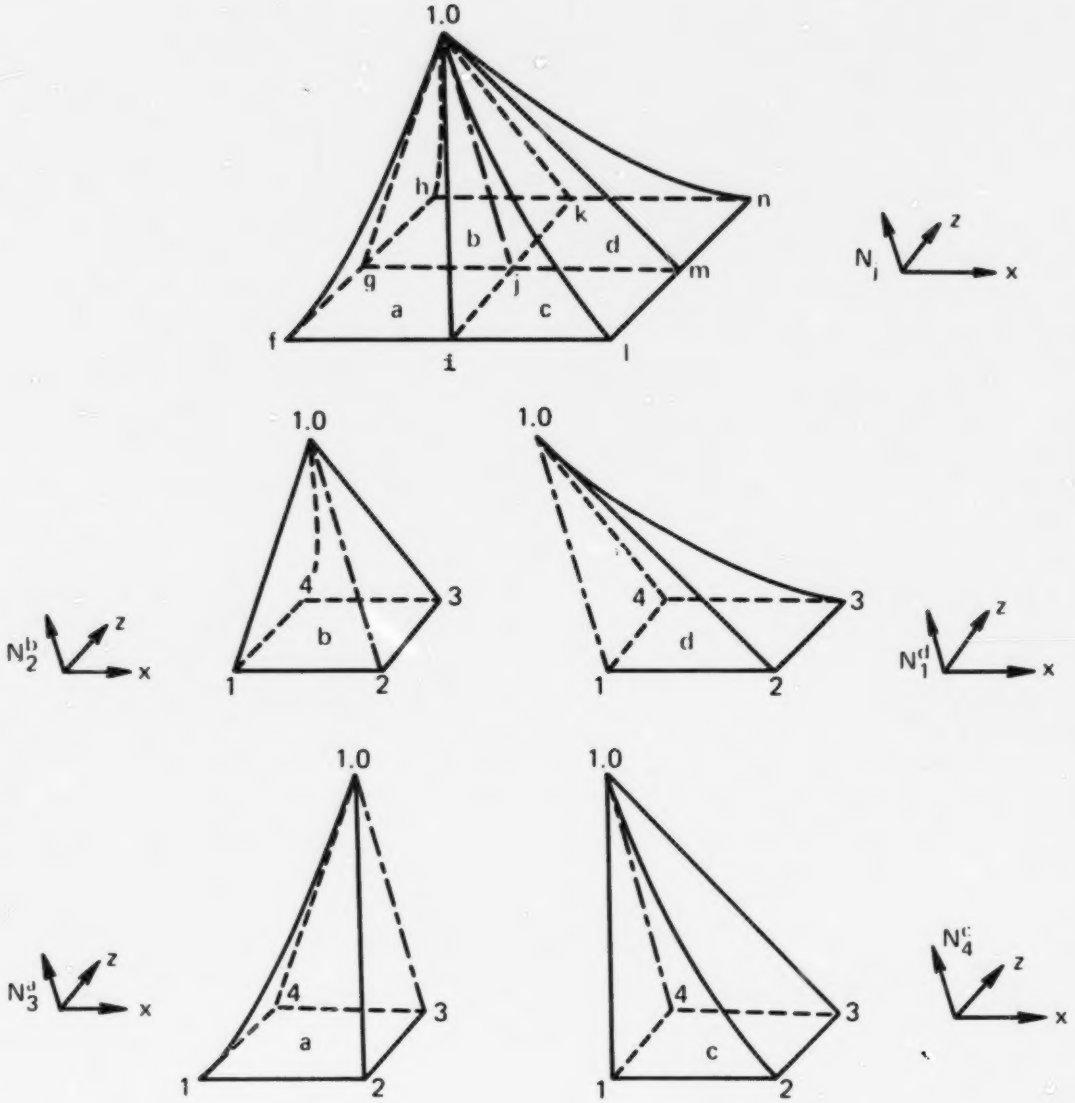

1.0
h
k
n
b
d
g
j
m
a
c
f
i
l
N_j
z
x
1.0
1.0
4
3
b
1
2
N_2^b
z
x
4
3
d
1
2
N_1^d
z
x
1.0
1.0
4
3
a
1
2
N_3^a
z
x
4
3
c
1
2
N_4^c
z
x

Fig. A-2. Definition of base functions over global region and each element where

N_f, N_g, N_h, N_i, N_j, N_k, N_l, N_m, N_n = base functions for nodes f, g, h, i, j, k, l, m, and n, respectively;

N_1^a, N_2^a, N_3^a, N_4^a = the first, second, third, and fourth-node base functions for element a;

N_1^b, N_2^b, N_3^b, N_4^b = the first, second, third, and fourth-node base functions for element b;

N_1^c, N_2^c, N_3^c, N_4^c = the first, second, third, and fourth-node base functions for element c; and

N_1^d, N_2^d, N_3^d, N_4^d = the first, second, third, and fourth-node base functions for element d.

In fact, the base function N_j is given by

$$N_j(x,z) = \frac{x - x_g}{x_j - x_g} \cdot \frac{z - z_i}{z_j - z_i} \quad \text{over element a} \quad , \tag{7a}$$

$$N_j(x,z) = \frac{x - x_g}{x_j - x_g} \cdot \frac{z_k - z}{z_k - z_j} \quad \text{over element b} \quad , \tag{7b}$$

$$N_j(x,z) = \frac{x_m - x}{x_m - x_j} \cdot \frac{z - z_i}{z_j - z_i} \quad \text{over element c} \quad , \tag{7c}$$

$$N_j(x,z) = \frac{x_m - x}{x_m - x_j} \cdot \frac{z_k - z}{z_k - z_j} \quad \text{over element d} \quad . \tag{7d}$$

Step 3 - Define weighting functions:

$$W_i(x,z) = N_i(x,z), \; i = 1,2,\ldots, N \quad . \tag{8}$$

Step 4 - Approximate the solution by linear combination of base functions:

$$h \simeq \hat{h} = \sum_{j=1}^{N} h_j(t)\, N_j(x,z) \quad . \tag{9}$$

Step 5 - Define residual R_r by

$$R_r = F \frac{\partial \hat{h}}{\partial t} - \nabla \cdot [\bar{\bar{K}} \cdot (\nabla \hat{h} + \nabla z)] \quad . \tag{10}$$

Step 6 - Set weighted residuals to zero:

$$\int_R W_i \left\{F \frac{\partial \hat{h}}{\partial t} - \nabla \cdot [K \cdot (\nabla \hat{h} + \nabla z)]\right\} dR = 0 \quad ,$$

$$i = 1,2,\ldots, N \quad . \tag{11}$$

Step 7 - Derive matrix equation:

Substituting Eq. (9) into Eq. (11) and integrating by part, we obtain

$$[\int_R N_i \, F \, N_j] \frac{dh_j}{dt} + [\int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j) \, dR] \, h_j$$

$$= - \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla z) \, dR + \int_\Gamma \vec{n} \cdot \bar{\bar{K}} \cdot (\nabla h + \nabla z) N_i \, d\Gamma \quad ,$$

$$i = 1,2,\ldots, N \quad . \tag{12}$$

Equation (12) written in matrix form is

$$[a]\,\frac{dh}{dt} + [b]\,\{h\} = \{D\} + \{Q\} \quad , \tag{13}$$

where $[a]$ = mass matrix,

$[b]$ = stiff matrix,

$\{D\}$ = known load vector, and

$\{Q\}$ = boundary load vector.

$$a_{ij} = \int_R N_i\, F\, N_j \, dR = \sum_{e \in M} \int_{R_e} N_i\, F\, N_j \, dR$$

$$= \sum_{e \in M_e} \int_{R_e} N^e_\alpha\, F\, N^e_\beta \, dR \tag{14}$$

in which M_e is the set of elements that have a local side $\alpha - \beta$ coinciding with the global side $i - j$.

Similarly,

$$b_{ij} = \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j)\, dR = \sum_{e \in M} \int_{R_e} (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j)\, dR =$$

$$\sum_{e \in M_e} \int_{R_e} (\nabla N^e_\alpha) \cdot \bar{\bar{K}} \cdot (\nabla N^e_\beta)\, dR \quad , \tag{15}$$

$$D_i = - \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot \nabla z \, dR = - \sum_{e \in M} \int_{R_e} (\nabla N_i) \cdot \bar{\bar{K}} \cdot \nabla z \, dR =$$

$$- \sum_{e \in M_e} \int_{R_e} (\nabla N^e_\alpha) \cdot \bar{\bar{K}} \cdot \nabla z \, dR \quad , \tag{16}$$

and

$$Q_i = \int_\Gamma \vec{n} \cdot \bar{\bar{K}} \cdot (\nabla h + \nabla z) N_i \, d\Gamma \quad . \qquad (17)$$

Step 8 - Incorporate boundary conditions into the matrix equation. If Eq. (4) or (5b) is applied to a boundary node, then Eq. (17) is integrated over the boundary segments that have the boundary node and the results are used as boundary load vector. On the other hand, if Eq. (3) or (5a) is applied to a boundary node, the integration of Eq. (17) can be ignored because an identity equation will be created for such node.

Step 9 - Solve the initial value problem, Eqs. (13) and (2).

A-IV. FEMWATER PROGRAM STRUCTURE

A-IV.1. Purpose of FEMWATER

The source program of FEMWATER is designed mainly to solve for the following initial and boundary value problem:

Governing Equation

$$F \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}[K_r\{K^s_{xx} \frac{\partial(h+z)}{\partial x} + K^s_{xz} \frac{\partial(h+z)}{\partial z}\}] + \frac{\partial}{\partial z}[K_r\{K^s_{zx} \frac{\partial(h+z)}{\partial x} + K^s_{zz} \frac{\partial(h+z)}{\partial z}\}] \quad , \qquad (1)$$

where h is the matric potential (pressure head); z is the gravitational head (potential head); x and z are the Cartesian coordinates on the vertical plane; t is the time; F is the generalized storage coefficient, a function of pressure h; K^s_{xx}, K^s_{xz}, K^s_{zx}, and K^s_{zz} are the four components of the saturated hydraulic conductivity tensor K^z; and K_r is the relative hydraulic conductivity, a function of pressure head h, resulting from expressing $\bar{\bar{K}} = \bar{\bar{K}}^s K_r$.

Initial Condition

$$h(x,z,0) = h_i(x,z,t) \text{ in } R \quad , \qquad (2)$$

where R is the region of interest and $h_i(x,z,t)$ is the prescribed initial value function, which may also be obtained by solving for h the steady-state version of Eq. (1) under time-invariant boundary conditions.

Boundary Conditions

$$h(x,z,t) = h_D(x_b,z_b,t) \quad \text{on} \quad B_D \quad , \tag{3}$$

$$- n_x[K_r\{K^s_{xx}\frac{\partial(h+z)}{\partial x} + K^s_{xz}\frac{\partial(h+z)}{\partial z}\}] - n_z[K_r\{K^s_{zx}\frac{\partial(h+z)}{\partial x} + K^s_{zz}\frac{\partial(h+z)}{\partial z}\}] =$$
$$= q_N(x_b,z_b,t) \quad \text{on} \quad B_N \quad , \tag{4}$$

and

$$h(x,z,t) = h_V(x_b,z_b,t) \quad \text{on} \quad B_V \tag{5a}$$

or

$$- n_x[K_r\{K^s_{xx}\frac{\partial(h+z)}{\partial x} + K^s_{xz}\frac{\partial(h+z)}{\partial z}\}] - n_z[K_r\{K^s_{zx}\frac{\partial(h+z)}{\partial x} +$$
$$K^s_{zz}\frac{\partial(h+z)}{\partial z}\}] = q_V(x_b,z_b,t) \quad \text{on} \quad B_V \quad , \tag{5b}$$

where $h_D(x_b,z_b,t)$ is the prescribed pressure head as a function of time t and spatial coordinate (x_b,z_b) on the Dirichlet boundary B_D; $q_N(x_b,z_b,t)$ is the prescribed water flux through the boundary, a function of the time t and spatial coordinate (x_b,z_b) on the Neumann boundary B_N; $h_V(x_b,z_b,t)$ and $q_V(x_b,z_b,t)$ are the prescribed pressure head and water flux through the boundary and both are functions of the time and spatial coordinate (x_b,z_b) on the Variable-type boundary B_V; and n_x and n_z are the x- and z-components, respectively, of a unit vector normal to the boundary outwardly. It should be noted that $q_N(x_b,z_b,t)$ and $q_V(x_b,z_b,t)$ are positive if they are directed out from the region of interest and negative if directed into the region. Only Eq. (5a) or (5b) can be applied to B_V at a time; they cannot be applied to B_V at the same time.

A-IV.2. Structure

The Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) consists of a MAIN program and 16 subroutines. These subroutines are named according to their functions. The MAIN program is utilized to specify the dimension of arrays and to assign integer parameters of the array sizes. It also initializes the arrays. The control and coordinate activity are performed by the subroutine GW2DXZ. Figure A-3 shows the structure of the model.

Subroutine GW2DXZ

The subroutine GW2DXZ controls the entire sequence of operations, a function generally performed by the MAIN program. It is, however, preferable to keep a short MAIN and several subroutines with variable storage allocation. This makes it possible to place most of the FORTRAN deck on a permanent file and to deal with a site-specific problem without making changes in the array dimensions throughout all subroutines.

The subroutine will perform either the steady-state computation alone (KSS = 0 and NTI = 0), or a transient computation using the steady-state as the initial condition (KSS = 0 and NTI > 0), or the transient computation using user-supplied initial conditions (KSS = 1 and NTI > 0). GW2DXZ calls to subroutine DATAIN for reading data; subroutine SPROP for obtaining the hydraulic conductivity, water capacity, and moisture content from the pressure head; subroutine VELT to compute Darcy's velocity; subroutine BCPREP to determine if a change

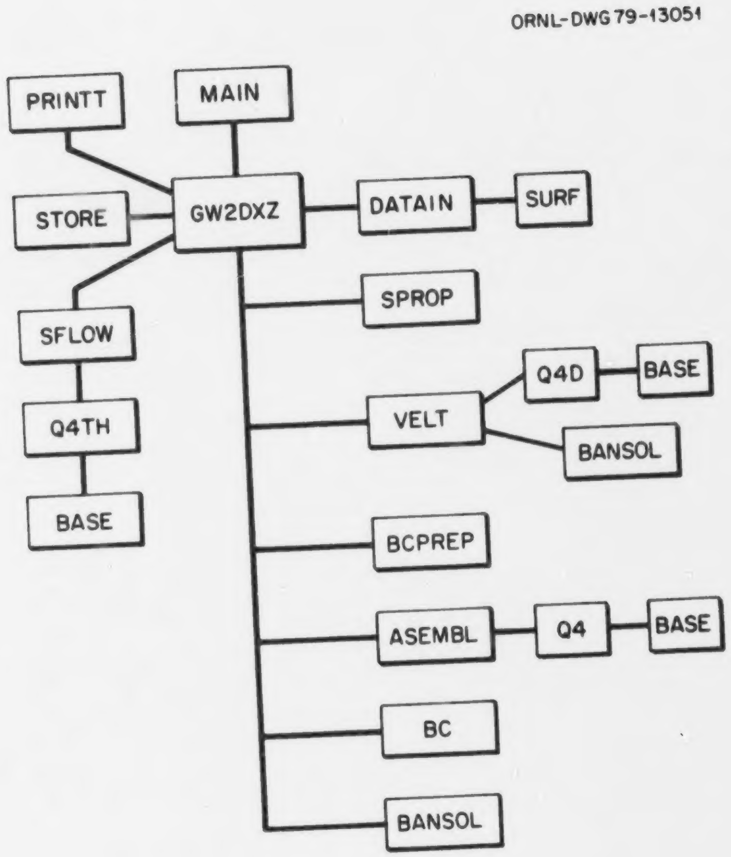

ORNL-DWG 79-13051
PRINTT
MAIN
STORE
GW2DXZ
DATAIN
SURF
SFLOW
SPROP
Q4D
BASE
Q4TH
VELT
BANSOL
BASE
BCPREP
ASEMBL
Q4
BASE
BC
BANSOL

Fig. A-3. FEMWATER program structure

from Dirichlet to Neumann boundary condition is required or vice versa; subroutine ASEMBL to assemble the element matrix over all elements; subroutine BC to implement Dirichlet, Neumann, and rainfall-seepage boundary conditions; subroutine BANSOL to solve the resulting matrix equation; subroutine SFLOW to calculate flux through all types of boundaries and moisture-content accumulated in the media; subroutine PRINTT to print out the results; and subroutine STORE to store the flow variables for input to a waste-transport model or for plotting.

Subroutine DATAIN

Subroutine DATAIN reads all data input described in Section A-IV.3 except the card group 1. It also prints all the input information and calls subroutine SURF to identify the surface elements and boundary nodes.

Subroutine SURF

Subroutine SURF identifies the boundary sides, sequences the boundary nodes, and computes the length and directional cosines of each side. The element numbers associated with the boundary sides are stored in NBE; the boundary nodes are stored in NPB. The length and directional cosines for each side are stored in DLB and DCOSXB and DCOSZB, respectively. The local and global nodal numbers of two nodes of each side are in ISB. The information is returned to the subroutine DATAIN for other users.

Subroutine SPROP

This subroutine calculates the values of moisture content, TH(M,IQ), the hydraulic conductivity components, AKX(M,IQ) and AKZ(M,IQ), and the water capacity, DTH(M,IQ) as functions of the pressure head, H(NP). Two options are available. One is to interpolate the values from the tabular input. The other is to compute the value with an analytical function characterized by a certain number of parameters. The maximum number of the parameters one can input is given by MXSPPM. When the analytical option is used, the user must supply the functional form. An example in the present code is given by cards SPRO 315 to SPRO 525. Any analytical function other than the example should be coded in lieu of the above FORTRAN statements.

Subroutine VELT

This subroutine calls to Q4D to evaluate the element matrix. It then sums over all element matrices to form a matrix equation governing the velocity components at all nodal points. Subsequently, it calls Subroutine BANSOL to yield the solution. The computed velocity field is then returned to GW2DXZ through the argument. The velocity field is then passed to Subroutine BCPREP to evaluate the Darcy flux across the seepage-rainfall surfaces.

Subroutine Q4D

Subroutine Q4D is called by the Subroutine VELT to compute the element matrix given by

$$QQ(I,J) = \int_{R_e} N_i N_j \, dR \quad ,$$

where N_i and N_j are the base functions for nodal points i and j, respectively. It also evaluates the element load vector given by

$$RQ(I) = -\int_{R_e} N_i \left[K_{xx} \frac{\partial N_j}{\partial x} h_j + K_{xz} \frac{\partial N_j}{\partial z} h_j + K_{xz}\right] dR$$

or

$$RQ(I) = -\int_{R_e} N_i \left[K_{zx} \frac{\partial N_j}{\partial x} h_j + K_{zz} \frac{\partial N_j}{\partial z} h_j + K_{zz}\right] dR \quad ,$$

where h_j is the pressure head at nodal point j and K_{xx}, K_{xz}, K_{zx}, and K_{zz} are hydraulic conductivity tensor components. The computation of these quantities is straightforward.

Subroutine BASE

This subroutine is called by Q4D, Q4TH, and Q4 to evaluate the value of the base function at a Gaussian point. The computation is straightforward.

Subroutine BANSOL

This subroutine is called by VELT and GW2DXZ to solve for the matrix equation of the type

$$[C]\,\{x\} = \{y\} \quad ,$$

where [C] is a matrix and {x} and {y} are two vectors. {x} is the unknown to be solved and {y} is the known load vector. The computer returns the solution {x} and stores it in {y}. The computation is a standard procedure.

Subroutine BCPREP

This subroutine is called by GW2DXZ to prepare the rainfall-seepage boundary conditions. It decides the number of nodal points on the rainfall-seepage boundaries to be considered as Dirichlet points and Neumann points. It also computes the number of points that change boundary conditions from Dirichlet to Neumann types or from Neumann to Dirichlet types. Upon completion, this subroutine returns the Darcy flux--DCYFLX, rainfall flux--FLX, the ponding depth nodal index--NPCON, the flux-type nodal index--NPFLX, and the number of nodal points--NCHG that have changed boundary conditions.

Subroutine ASEMBL

This subroutine calls Q4 to evaluate the element matrix. It then sums over the entire element matrix to form a matrix equation governing the pressure head at all nodal points.

Subroutine Q4

Subroutine Q4 is called by ASEMBL to compute the element matrix given by

$$QA(I,J) = \int_{R_e} N_i F N_j \, dR$$

and

$$QB(I,J) = \int_{R_e} \left[\frac{\partial N_i}{\partial x}\left(K_{xx}\frac{\partial N_j}{\partial x} + K_{xz}\frac{\partial N_j}{\partial z}\right) + \frac{\partial N_i}{\partial z}\left(K_{zx}\frac{\partial N_j}{\partial x} + K_{zz}\frac{\partial N_j}{\partial z}\right)\right] dR$$

where F is the soil property function and K_{xx}, K_{xz}, and K_{zz} are the tensor components of the hydraulic conductivity. It also evaluates the load vector given by

$$RQ(I) = \int_{R_e} \left(K_{xz}\frac{\partial N_i}{\partial x} + K_{zz}\frac{\partial N_i}{\partial z}\right) dR \quad ,$$

Subroutine BC

This subroutine evaluates both Dirichlet and Neumann boundary conditions. For a Dirichlet boundary condition, an identity algebraic equation is generated for each Dirichlet nodal point. Any other equation having this nodal variable is modified accordingly to simplify the computation. For the Neumann boundary-side, the integration of the surface source is added to the load vector. The subroutine BC also implements the variable boundary conditions. First, it checks over all rainfall-seepage points, identifying any of them that are Dirichlet points. If any are Dirichlet points, the method of incorporating Dirichlet boundary conditions mentioned above is used. If a given point is not, the point is bypassed. Second, it checks over all rainfall-seepage points again to see if any of them are Neumann points. If any are, the computed flux by the rainfall is added to the load vector. If a given point is not a Neumann point, it is bypassed. Because the rainfall-seepage points are either Dirichlet or Neumann points, all points are taken care of in this manner.

Subroutine PRINTT

This subroutine is used to line-print the flow variables. These include the fluxes through variable boundary segments, the pressure head, total head, moisture head, and Darcy's velocity components.

Subroutine STORE

This subroutine is used to store the flow variables on logical unit 1. It is intended for use with a subsequent computer model, FEMWASTE. The information stored includes TITLE, NPROB, NNP, NEL, NBN, NBEL, NTI, NRSN, X, Z, IE, DCOSXB, DCOSZB, NBE, ISB, and TIME, H, HT, TH, VX, VZ, NPCON, NPFLX for each desired time step.

Subroutine SFLOW

This subroutine is used to compute the fluxes through various types of boundaries and the increasing rate of moisture content in the region of interest. FLOW(6) is to store the flux through the whole boundary enclosing the region of interest. It is given by

$$\mathrm{FLOW(6)} = \int_B (V_x n_x + V_z n_z)\, dB \quad ,$$

where B is the global boundary of the region of interest, V_x and V_z are the Darcian velocity components on the boundary in the x- and z-direction, respectively, and n_x and n_z are the directional cosines of the outward unit vector normal to the boundary B. FLOW(1) through FLOW(4) store the flux through Dirichlet boundary B_D, Neumann boundary B_N, the seepage boundary B_S, and the rainfall infiltration boundary B_R, respectively, and are given by

$$\mathrm{FLOW(1)} = \int_{B_D} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$\mathrm{FLOW(2)} = \int_{B_N} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$\mathrm{FLOW(3)} = \int_{B_S} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$\mathrm{FLOW(4)} = \int_{B_R} (V_x n_x + V_z n_z)\, dB \quad .$$

FLOW(5), which is related to the numerical loss, is given by

$$\text{FLOW}(5) = \text{FLOW}(6) - [\text{FLOW}(1) + \text{FLOW}(2) + \text{FLOW}(3) + \text{FLOW}(4)] \quad .$$

If there is no numerical error in the computation, FLOW(6) should be equal to FLOW(7) to be defined below and FLOW(5) should be equal to zero. FLOW(7) is used to store the moisture-content increasing rate within the porous media; that is,

$$\text{FLOW}(7) = \int_R F \frac{\partial h}{\partial t} dR \quad ,$$

where F is the soil property function and h is the pressure head.

Subroutine Q4TH

This subroutine is used to compute the contribution of moisture-content increasing rate from an element:

$$\text{QTHP} = \int_{R_e} \left(\frac{d\theta}{dh} + \theta\alpha'/n_e + \beta'\right)\frac{\partial h}{\partial t} dR$$

where α' and β' are the modified compressibility of the soil matrix and liquid fluid, respectively, n_e is the effective porosity, and θ is the moisture-content. The computation of the above integration is straight-forward.

A-V. FEMWATER PROGRAM REQUIREMENTS AND INPUT DATA GUIDE

The following describes the requirements for each site-specific application and the input data guide.

A-V.1. Variable Array Dimension Specification

The subscripted variable arrays have to be dimensioned for each site-specific problem in the main program. Fourteen (14) cards containing the following variables should be dimensioned according to the subscript in each of the arrays:

X(MAXNP),Z(MAXNP),IE(MAXEL,5)	1 card
C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP), HP(MAXNP),HW(MAXNP),HT(MAXNP), TH(MAXZL,4),DTH(MAXZL,4),VX(MAXNP), VZ(MAXNP),AKX(MAXEL,4)AKZ(MAXEL,4), NPCNV(MAXNP)	3 cards
DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZ(MAXBEL), BFLX(MAXBNP),BFLXP(MAXBNP),NBE(MAXBEL), ISB(MAXBEL,4),NPB(MAXBNP)	2 cards
DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL), DCYFLX(MXRSNP),FLX(MXRSNP),RSFLX(MXRSNP), HCON(MXRSNP),NRSE(MXRSEL),IS(MXRSEL,4), NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP), IRFTYP(MXRSNP),TRF(MXRFPR,MXRPAR), RF(MXRFPR,MXRPAR),RFALL(MXRFPR)	3 cards
RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)	1 card
PROP(MAXMAT,MXMPPM),THPROP(MAXMAT,MXSPPM), AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM), CAPROP(MAXMAT,MXSPPM)	2 cards
PMAT(3,MXMPPM),AKPAR(3,NAKPPM),THPAR(3,NTHPPM)	1 card
KPR(MAXNTI),KDSK(MAXNTI)	1 card

where MAXNP is the maximum number of nodal points; MAXEL, the maximum number of elements; MAXBEL, the maximum number of boundary element-sides; MAXBNP, the maximum number of boundary nodal points; MXRSEL, the maximum number of rainfall seepage element-sides; MXRSNP, the maximum number of rainfall-seepage nodal points; MXRFPR, the maximum number of rainfall profiles; MXRPAR, the maximum number of rainfall parameters; MXSTNP, the maximum number of surface-term nodal points (the maximum number of Neumann boundary points); MAXBCN, the maximum number of Dirichlet boundary condition nodal points; MAXMAT, the maximum number of material types; MXMPPM, the maximum number of material properties per material type; MXSPPM, the maximum number of soil property points per material; MAXNTI, the maximum number of time integration steps; NAKPPM, the number of parameters per material to describe the conductivity parameter names; NTHPPM, the number of parameter per material to describe the moisture content parameter names; and MAXHBP, the maximum number of half band width plus 1 of the global matrix. For example, the seepage pond problem is dimensioned as follows:

```
 DIMENSION X(595),Z(595),IE(528,5)                                  MAIN 170

 DIMENSION C(595,16),R(595),H(595),HP(595),HW(595),HT(595),         MAIN 180
>TH(528,4),DTH(528,4),VX(595),VZ(595),                              MAIN 185
>AKX(528,4),AKZ(528,4),NPCNV(595)                                   MAIN 190

 DIMENSION DLB(199),DCOSXB(199),DCOSZB(199),BFLX(200),BFLXP(200),   MAIN 200
>NBE(199),ISB(199,4),NPB(200)                                       MAIN 205

 DIMENSION DL(99),DCOSX(99),DCOSZ(99),DCYFLX(100),FLX(100),         MAIN 215
>RSFLX(100),HCON(100),NRSE(99),IS(99,4),NPRS(100),NPCON(100),       MAIN 220
>NPFLX(100),IRFTYP(100),TRF(3,20),RF(3,20),RFALL(3)                 MAIN 225

 DIMENSION RP(30),NPST(30),BB(40),NN(40)                            MAIN 235
```

```
      DIMENSION PROP(3,5),THPROP(3,52),AKPROP(3,52),HPROP(3,52)         MAIN 245
     >CAPROP(3,52)                                                      MAIN 250
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8)                         MAIN 255
      DIMENSION KPR(250),KDSK(250)                                      MAIN 265
```

Corresponding to the above dimension specification cards, six data specification cards must be used to assign the control number; for example:

```
      DATA MAXEL,MAXNP,MAXHBP/528,595,16/                          MAIN 335
      DATA MAXBEL,MAXBNP/199,200/                                  MAIN 340
      DATA MXRSEL,MXRSNP,MXRFPR,MXRPAR/99,100,3,20/                MAIN 345
      DATA MXSTEL,MXSTNP,MAXBCN/29,30,40/                          MAIN 350
      DATA MAXMAT,MXSPPM,MXMPPM,NTHPPM,NAKPPM/3,52,5,8,8/          MAIN 355
      DATA MAXNTI/250/                                             MAIN 360
```

where MAXHBP is the maximum number of half band width of matrix C.

A-V.2. Soil Property Function Specifications

The code provides two options to handle the functional relationships of moisture-content, water-capacity, and hydraulic conductivity with the pressure head. One is the tabular input while the other is the analytic function specification. If the former option is used, the user may ignore this subsection. If the latter is used, the user must supply three functions to compute the moisture-content, hydraulic conductivity, and water capacity based on the current value of pressure head. The parameters needed to specify these functional forms are read and stored in AKPROP and THPROP arrays. One example is shown in the subroutine SPROP (Appendix A) when KSP = 0.

A-V.3. Input Data Guide

The input format for each data card is specified in the following. The number under the drawing is the last column of each field. In general, an integer has a field length of 5 and should be right-justified. On the other hand, a real number has a field length of 10 and can be placed anywhere within the field.

1. Title

Format (I5,9A8,IX,2I1). One card per problem:

NPROB	TITLE		IBUG	ICHNG
5	77	78	79	80

NPROB = Problem number.

TITLE(9) = Array for the title of the problem.

IBUG = Integer control number indicating if the diagnostic output is desired: = 0, no; = 1, yes.

ICHNG = Integer control number indicating if the cyclic change of rainfall-seepage nodes is to be printed: = 0, no; = 1, yes.

2. Basic Integer Parameters

Two cards per problem are required.

Card 1: Format (16I5):

NNP	NEL	NMAT	NCM	NTI	KSS	KSP	NSPPM
5	10	15	20	25	30	35	40

KSTR	KCP	KGRAV	NSTRT	MAXIT	MAXCY	NMPPM	☒
45	50	55	60	65	70	75	80

NNP = Number of nodal points.

NEL = Number of elements.

NMAT = Number of materials.

NCM = Number of elements with material property correction.

NTI = Number of time increments.

KSS = Steady state control; 0 = steady solution, 1 = transient.

KSP = Soil property control; 0 = analytical, 1 = tabular data.

NSPPM = Number of points in tabular soil property functions or number of parameters to specify analytical soil functions per material.

KSTR = Auxiliary storage output control; 0 = no storage, 1 = output stored in logical unit 1 (disk or tape).

KCP = Permeability input control; 0 = input conductivity, 1 = input permeability.

KGRAV = Gravity term control; 0 = no gravity, 1 = include gravity.

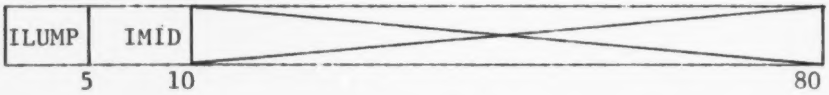
NSTRT = Number of logical records to be read from auxiliary storage for restarting calculations; 0 = no restart.

MAXIT = Maximum number of iterations per cycle.

MAXCY = Maximum number of cycles permitted for iterating rainfall-seepage boundary conditions per time step.

NMPPM = Number of material properties per material, = 5 for the present.

Card 2: Format (16I5):



ILUMP = Mass matrix lumping control; 0 = no lumping, 1 = lumping.

IMID = Mid-difference integration control; 0 = no,

1 = mid-difference.

3. Basic Real Parameters

Two cards per problem. Use of an E-, D-, or another F-type field specification in the input card overrides any of the F10.0 specifications of the format.

Card 1: Format (8F10.0):

DELT	CHNG	DELMAX	TMAX	FE	TOLA	TOLB	RHO
10	20	30	40	50	60	70	80

DELT = Time increment (T).

CHNG = Multiplier for increasing time increment.

DELMAX = Maximum value of DELT (T).

TMAX = Value of maximum simulation time (T).

FE = Angle between coordinate axes and principal directions of conductivity tensor in degrees.

TOLA = Steady-state convergence criteria (L).

TOLB = Transient-state convergence criteria (L).

RHO = Density of water (ML^{-3}).

Card 2: Format (8F10.0):

GRAV	VISC	W	☒
10	20	30	

GRAV = Acceleration of gravity (LT^{-2}).

VISC = Dynamic viscosity of water ($ML^{-1}\ T^{-1}$).

W = Time derivative weighting; 0.5 = Crank-Nicolson, 1.0 = backward.

4. Printer Output and Disk Store Control: FORMAT(80I1).

The number of cards here depends on the number of time increments, NTI. The number of cards is (NTI/80 + 1)*2. (NTI/80 + 1) cards for printer output control and (NTI/80 + 1) cards for store control:

KPRO	KPR(1)	KPR(2)	. . .	KPR(NTI)
1	2	3		

KDSKO	KDSK(1)	KDSK(2)	. . .	KDSK(NTI)
1	2	3		

KPRO = Printer control for steady state and initial conditions;) = print nothing, 1 = print FLOW, FRATE, TFLOW only, 2 = print above (1) plus H, 3 = print above (2) plus HT, 4 = print above (3) plus TH, 5 = print above (4) plus VX and VZ.

KPR(ITM) = Printer control for transient solution similar to KPRO as function of time index ITM.

KDSKO = Disk storage control for steady-state and initial control; 0 = no storage, 1 = store on logical unit 1.

KDSK(ITM) = Disk storage control for transient solution similar to KDSKO as a function of time index ITM.

5. Material Properties: FORMAT(8F10.0).

A total of NMAT groups of cards, one for each of the materials:

PROP(1,1)	PROP(1,2)	. . .	PROP(1,NMPPM)
	⋮		
PROP(NMAT,1)	PROP(NMAT,2)	. . .	PROP(NMAT,NMPPM)
10	20		

PROP(J,1) = Modified coefficient of compressibility of media J (L^{-1}).

PROP(J,2) = Modified coefficient of compressibility of water J (L^{-1}).

PROP(J,3) = Effective porosity of media J.

PORO(J,4) = xx-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability tensor (L^2).

PROP(J,5) = zz-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability tensor (L^2).

6. Analytic Soil Parameters: FORMAT(8F10.0).

These cards are input, if and only if KSP = 0. Two sets of cards per material--one for moisture-content parameters and the other for conductivity (permeability) parameters. The number of cards per set is determined both by the number of parameters used to specify the soil property per material, NSPPM, and by the number of materials, NMAT:

THPROP(1,1)	THPROP(1,2)	. . .	THPROP(1,NSPPM)
		⋮	
THPROP(NMAT,1)	THPROP(NMAT,2)	. . .	THPROP(NMAT,NSPPM)
AKPROP(1,1)	KAPROP(1,2)	. . .	AKPROP(1,NSPPM)
		⋮	
AKPROP(NMAT,1)	AKPROP(NMAT,2)	. . .	AKPROP(NMAT,NSPPM)
10	20		

THPROP(J,I) = Analytical moisture-content parameter I of material J.

AKPROP(J,I) = Analytical relative conductivity parameter I of material J.

7. Soil Properties in Tabular Form: FORMAT(8F10.0).

These cards are input if and only if KSP ≠ 0. Four sets of cards per material--one each for pressure, water-content, relative conductivity (or relative permeability), and water capacity, respectively. The number of cards per set is determined by input parameters, NSPPM and NMAT:

HPROP(1,1)	HPROP(1,2)	. . .	HPROP(1,NSPPM)
		⋮	
HPROP(NMAT,1)	HPROP(NMAT,2)	. . .	HPROP(NMAT,NSPPM)
10	20		

THPROP(1,1)	THPROP(1,2)	. . .	THPROP(1,NSPPM)
		⋮	
THPROP(NMAT,1)	THPROP(NMAT,2)	. . .	THPROP(NMAT,NSPPM)
AKPROP(1,1)	AKPROP(1,2)	. . .	AKPROP(1,NSPPM)
		⋮	
AKPROP(NMAT,1)	AKPROP(NMAT,2)	. . .	AKPROP(NMAT,NSPPM)
CAPROP(1,1)	CAPROP(1,2)	. . .	CAPROP(1,NSPPM)
		⋮	
CAPROP(NMAT,1)	CAPROP(NMAT,2)	. . .	CAPROP(NMAT,NSPPM)
10	20		

HPROP(J,K) = Tabular values of pressure head of K-th point for material J (L).

THPROP(J,K) = Tabular values of moisture-content of K-th point for material J (L^3/L^3).

AKPROP(J,K) = Tabular values of relative conductivity (or relative permeability) of K-th point for material J.

CAPROP(J,K) = Tabular values of specific moisture-content capacity of K-th point for material J (L^{-1}).

8. Nodal-Point Positions: FORMAT(I5,2F10.3).

Usually one card per node is needed, i.e., a total of NNP cards. However, if some nodes fall on a straight line and are equidistant, data for only the first and last points of this group are needed. Intermediate nodal positions are automatically generated by linear interpolation:

NJ	X(NJ)	Z(NJ)	☒
5	15	25	80

⋮

NJ = Node number.

X(NJ) = X-coordinate of node NJ (L).

Z(NJ) = Z-coordinate of node NJ (L).

9. Element Definitions: FORMAT(16I5).

Usually one card per element is needed, i.e., a total of NEL cards:

MI	IE(MI,1)	. . .	IE(MI,5)	MODL	NLAY	☒
5	10	25	30	35	40	80

⋮

MI = Element number.

IE(MI,1) = Global nodal number of the first node of element MI.

IE(MI,2) = Global nodal number of the second node of element MI.

IE(MI,3) = Global nodal number of the third node of element MI.

IE(MI,4) = Global nodal number of the fourth node of element MI.

IE(MI,5) = Material type of element MI.

MODL = Number of elements in width.

NLAY = Number of elements in length.

IE(MI,1) to IE(MI,4) are the nodal numbers of element MI (beginning with the lower left and progressing around the element in a counterclockwise direction), and IE(MI,5) is the material type MTYP. For rectangular blocks of elements--the same material having sequentially numbered nodes--it is necessary to specify only the first element, the width MODL, and the length NLAY, where MODL and NLAY are measured in elements. Element numbering proceeds most rapidly along the MODL dimension and least rapidly along the NLAY dimension (Fig. A-4 provides an example). The object is considered to be rectangular because it has width MODL = 3 on two opposite sides and length NLAY = 5 on the other two sides. To generate definitions of elements 2 through 15 automatically, including both corner node identification and material type, only one card is necessary:

1	1	5	6	2	1	3	5	
5	10	15	20	25	30	35	40	80

Although all elements of this example will be assumed to contain the same material, MTYP = 1, this situation can easily be changed by using the material-correction facility.

ORNL-DWG 81-3924 ESD

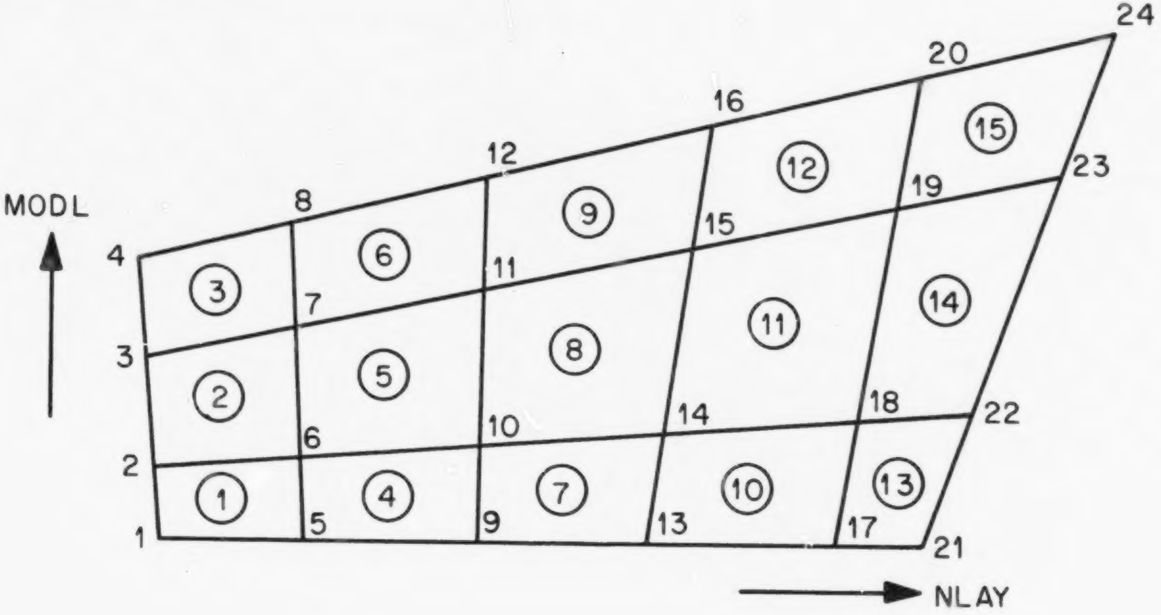

MODL
NLAY
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭
⑮

Fig. A-4. Example of the automatic generation of elements

10. Material Correction: FORMAT(16I5).

In many cases one card is required per material change. However, in those cases where numbers of the affected elements range from a lower limit of MI to an upper limt of MK with an increment MINC, automatic correction may be used. Fields MK and MINC are left blank if the automatic-generation facility is not used:

MI	MTYP	MK	MINC	☒
5	10	15	20	80

⋮

MI = Material correction element number.

MTYP = Type of material correction element.

MK = Upper limit of automatic correction.

MINC = Element increment of automatic correction (MK = 0 and MINC = 0 for no automatically generated correction).

11. Card Input for Initial or Pre-initial Conditions:

FORMAT(I5,5X,F10.0).

These cards are necessary only if NSTRT = 0. In the most general case there is one card per node, i.e., a total of NNP cards:

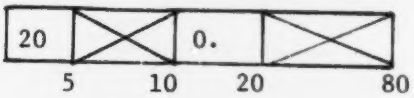
NJ	☒	H(NJ)	☒
5	10	20	80

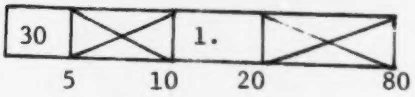
⋮

NJ = Nodal number.

H(NJ) = Initial or pre-initial pressure head of node NJ, (L).

Frequently, however, groups of neighboring nodal points NJ have identical values H(NJ). If a gap is recognized in the input sequence of nodal numbers, the intial pressures are assumed to be identical to the pressure at the lower boundary of the gap. For example, if two neighboring cards of the form





where encountered, nodes 21 to 29 would be assigned values of H = 0.0.

Note on initial conditions and restarting: The initial condition for a transient calculation may be obtained in three different ways: from card input, auxiliary storage input (referred to as tape input in discussion to follow), or steady-state calculation using a different set of boundary conditions than that used for transient calculation. In the latter case a card input of, shall we say, the pre-initial condition is required as the zero-th order iterate of the steady-state solution. Tape input is necessary whenever the restarting facility is being used. That is, pressure distributions for NSTRT different times have been generated and written on a magnetic tape. If NSTRT > 0, these distributions will be read from the tape, and the NSTRT-th distribution will be used as the initial condition for the current calculation. (If KSTR > 0, the pressure values will be written on a different magnetic tape as they are being read so that a complete record of the calculations may be kept on one tape.) If either the first (card-input) or the last (steady-state) option is desired, then NSTRT = 0.

Note on auxiliary storage units: Logical unit 1 is used for output if KSTR = 0, and logical unit 2 is used for input if NSTRT > 0. Proper identification of these units must be made in the job control language if either of these two options is used.

Note on steady-state input: The steady-state option may be used to provide either the final state of a system under study or the initial condition for a transient calculation. In the former case KSS = 0 and NTI = 0, whereas in the latter KSS = 0 and NTI > 0. If KSS = 0, there will be no steady-state calculation. Use of a steady-state as an initial condition requires a different set of boundary conditions than is used for the transient calculations. (A transient calculation using the same set of boundary conditions would not be meaningful because no changes in the pressure distributions could occur.) Input Data Sets 12 to 17, described below, define the steady-state boundary conditions. They are, of course, necessary if and only if KSS = 0.

12. Integer Parameters for Steady-state (KSS = 0, NTI = 0) or Transient (KSS = 1): FORMAT(16I5).

One card per problem is required:

NBC	NST	NRFPR	NRFPAR	NRSEL	NRSN	
5	10	15	20	25	30	80

NBC = Number of constant Dirichlet nodes.

NST = Number of elements with Neumann conditions.

NRFPR = Number of rainfall profiles.

NRFPAR = Number of parameters in each rainfall profile.

NRSEL = Number of rainfall-seepage element sides.

NRSN = Number of rainfall-seepage nodes.

13. Rainfall Profiles: FORMAT(8F10.0).

These cards are necessary if and only if the number of rainfall-seepage nodes NRSN > 0 and the number of rainfall profiles NRFRP > 0. If NRSN > 0 and NRFPR = 0, a rainfall rate of zero is assumed. The number of cards required will depend on both NRFPR and NRFPAR, the number of parameters within each profile:

TRF(1,1)	TRF(1,2)	. . .	TRF(1,NRFPAR)
RF(1,1)	RF(1,2)	. . .	RF(1,NRFPAR)
		⋮	
TRF(NRFPR,1)	TRF(NRFPR,2)	. . .	TRF(NRFPR,NRFPAR)
RF(NRFPR,1)	RF(NRFPR,2)	. . .	RF(NRFPR,NRFPAR)

Only the linearly interpolated value of the rainfall rate RF at time TRF = 0 will be used in the steady-state calculation. (See Data Set 19, below.)

TRF(I,J) = J-th interpolation time for rainfall profile I (T).

RF(I,J) = J-th interpolation value of rainfall for rainfall profile I (L).

14. Rainfall Type and Ponding Depth: FORMAT(3I5,5X,2F10.0).

Card input is required here if and only if NRSN > 0. Typically one card is required per rainfall-seepage node as follows:

NI	IRFTYP(NI)	NPINC	☒	HCON(NI)	☒
5	10	15	20	30	80

⋮

However, if NPINC ≠ 0, this information is automatically generated. If the card immediately preceding is for node NJ, then nodes NJ + NPINC, NJ + 2*NPINC, ..., NK will be given rainfall type IRFTYP(NJ) and puddling depth HCON(NJ), where NK is the largest integer in the above sequence that is less than the current nodal value NI. Rainfall type values IRFTYP(NI) > 0 are permitted. If the value is zero, then a rainfall rate of zero is assumed for node NI. If the value is greater than zero, then IRFTYP(NI) serves as a pointer to a rainfall profile input under Data Set 13, which is to be used to obtain the rainfall rate at node NI.

NI = Node number of rainfall type and ponding depth.

IRFTYP(NI) = Rainfall-type parameter used to identify the rainfall profile to be used at node NI.

NPINC = Automatic generation increment.

HCON(NI) = Ponding depth at node NP (L).

15. Rainfall-Seepage Surface Element Sides: FORMAT(16I5).

As in the two previous input sets, input is necessary here if and only if rain falls on surfaces or seepage flows through surfaces, or both, i.e., NRSN > 0. Typically, one card is required for each side of each element on which such a boundary is to be applied:

NRSE(MP)	IS(MP,1)	IS(MP,2)	KINC	☒
5	10	15	20	80

⋮

NRSE(MP) = Element number of MP--the rainfall-seepage element-side.

IS(MP,1) = Global node number of the first nodal point of MP--the rainfall-seepage element-side.

IS(MP,2) = Global node number of the second nodal point of MP--the rainfall-seepage element-side.

KINC = Automatic generation indicator for NRSE and IS.

However, if KINC > 0, automatic generation is employed in the following manner. Nodal-point and element number increments are formed from information on the input card immediately preceding the current one:

$$\mathrm{NPINC} = \mathrm{IS(MP,2)} - \mathrm{IS(MP,1)}$$

and

$$\mathrm{MINC} = |\mathrm{NPINC}| - 1 \quad ,$$

where the vertical bars denote absolute value. A sequence of element numbers is then obtained:

M = NRSE(MP) (previous card)
NRSE(MP+1) = M + MINC
NRSE(MP+2) = M + 2*MINC
⋮

The sequence is continued until the largest element number is encountered that has a value less than NRSE of the current card. Corresponding nodal point sequences are also generated:

NI = IS(MP,1) (previous card)
IS(MP+1,1) = NI + NPINC
IS(MP+2,1) = NI + 2*NPINC
⋮

and

NJ = IS(MP,2)
IS(MP+1,2) = NJ + NPINC
IS(MP+2,2) = NJ + 2*NPINC
⋮

16. Dirichlet Boundary Conditions: FORMAT(2I5,F10.0).

These cards are necessary if and only if NBC > 0 (and KSS = 0, a condition either stated or implied for the last four sets of cards). If automatic generation is not used (NPINC = 0), NBC cards are required of the form

NN(NPP)	NPINC	BB(NPP)	
5	10	20	80

⋮

NN(NPP) = Dirichlet node number.

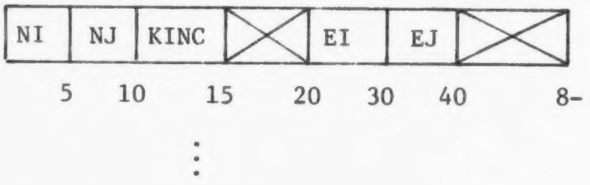
NPINC = Automatic generation increment for NN.

BB(NPP) = Dirichlet pressure at node NN (L).

If NPINC > 0, automatic generation proceeds in the same manner as described for Data Set 14. That is, an algebraic sequence is built on the nodal number NN of the card immediately preceeding, and each such node is given boundary condition BB of that card.

17. Neumann Boundary Conditions: FORMAT(3I5,5X,2F10.0).

Cards of this type must be used if and only if NST > 0. Usually a number of cards equal to NST must be used. However, if some of the KINC are greater than zero, some of the NST boundary conditions will be generated internally, and NST cards will not be necessary.



NI = Neumann flux node number.

NJ = Neumann flux node number.

KINC = Automatic gneration indicator for NI and NJ.

EI = Dot product of flux at NI with outwardly directed unit vector normal to element-side (NI,NJ).

EJ = Similar to EI.

If KINC > 0, then the nodal-point increment is formed from NI and NJ of the immediately preceding card:

$$NPINC = |NJ - NI| \; .$$

Two sequences are formed:

NI + NPINC, NI + 2*NPINC . . .

NJ + NPINC, NJ + 2*NPINC . . .

Both are terminated when the largest integer is reached that is less than both current values of NI and NJ. Corresponding nodal points for these two sequences define a surface. Quantity EI is the dot product of the flux of NI with an outwardly directed unit vector normal to the element side (NI,NJ). A similar definition holds for EJ.

Note on transient-state input: Data Sets 18 to 23 which follow are identical to Sets 12 to 17 used to define the boundary conditions for the steady-state calculation. Most of the remarks regarding automatic generation, sign conventions, and other input restrictions that are pertinent there are pertinent here as well. Cards, whose descriptions follow, are necessary only if NTI > 0. If NTI = 0, there will be no transient calculation, and transient-state boundary conditions are unnecessary. All variable definitions in card groups 19 through 25 below are the same as those in card groups 12 through 18.

18. Transient-State Integer Parameters (KSS=0,NTI=0): FORMAT(16I5). One card per problem.

NBC	NST	NRFPR	NRFPAR	NRSEL	NRSN	
5	10	15	20	25	30	80

19. Rainfall Profiles: FORMAT(8F10.0).

These cards are necessary if and only if the number of rainfall seepage nodes NRSN > 0 and the number of rainfall profiles NRFPR > 0.

TRF(1,1)	TRF(1,2)	. . .	TRF(1,NRFPAR)

RF(1,1)	RF(1,2)	. . .	RF(1,NRFPAR)

⋮

TRF(NRFPR,1)	TRF(NRFPR,2)	. . .	TRF(NRFPR,NRFPAR)

RF(NRFPR,1)	RF(NRFPR,2)	. . .	RF(NRFPR,NRFPAR)

This input provides the basic data for a linear interpolation from which the rainfall rate RF may be obtained at any time TRF and at any boundary node, as specified by pointer indices IRFTYP.

20. Rainfall Types and Ponding Depth: FORMAT(3I5,5X,2F10.0).

Card input is required here if and only if NRSN > 0.

NI	IRFTYP(NI)	NPINC	☒	HCON(NI)	☒
5	10	15	20	30	80

⋮

21. Rainfall-seepage Surface Element-sides: FORMAT(16I5).

Input is required if and only if NRSN > 0.

NRSE(MP)	IS(MP,1)	IS(MP,2)	KINC	☒
5	10	15	20	80

⋮

22. Dirichlet Boundary Conditions: FORMAT(2I5,2F10.0).

These cards are necessary if and only if NBC > 0.

NN(NPP)	NPINC	BB(NPP)	☒
5	10	20	80

⋮

23. Neumann Boundary Conditions: FORMAT(3I5,2F10.0).

Cards of this type must be used if and only if NST > 0.

NI	NJ	KINC	☒	EI	EJ	☒
5	10	15	20	30	40	80

⋮

A-VI. UNIQUENESS AND LIMITATIONS OF FEMWATER

The uniqueness of the FEMWATER code is given below:

* Treatment of Variable Boundary Conditions
* Three Options of Obtaining Initial Conditions
* Six Options of Solution Strategies listed in Table A.1

The limitations of FEMWATER lie in the availability of soil property function and computer storage:

* Need Two Curves for Each Material Type
* Need Large Amount of Computer Storage

Table A.1. Listing of Alternative Numerical Schemes*

	Time-marching			Mass matrix	
Numerical schemes	Central difference	Backward difference	Mid-difference	Without lumping	With lumping
1	X			X	
2		X		X	
3	X				X
4		X			X
5			X	X	
6			X		X

*In general, numerical scheme 1 is prefered because it has the second-order accuracy in time. However, if oscilation occurs, numerical scheme 2 is preferred. If both numerical schemes 1 and 2 fail, one should try all other alternative schemes. As a rule of thumb, a mass lumping scheme (numerical scheme 3, 4, or 6) yields more stable but less accurate results.

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APPENDIX B: COURSE PROBLEMS

B-I. A SIMPLE ONE-DIMENSIONAL PROBLEM

B-II. A SEEPAGE DRAINAGE PROBLEM

B-III. A SOLID WASTE DISPOSAL AREA PROBLEM

B-IV. A SHALLOW TRENCH BURIAL PROBLEM

APPENDIX B: COURSE PROBLEMS

In this class note, four example problems are used to illustrate the application of the FEMWATER code to low-level waste disposals in the shallow land system. The first example (B-I) is the study of vertical infiltration. It is typical of column tests, lysimetric experiments, or infiltrations by precipitation over flat horizontal ground surface. The second example is the study of water moving from a seepage pond into groundwater and to the stream. This typifies a class of problems involving leaching of wastes such as uranium mill tailings. The third (B-III) and fourth (B-IV) examples are the investigation of near-surface disposal of solid wastes and shallow trench burials, respectively. They are representative of dry or wet burials above the groundwater table with surface sealing.

In addition, these four examples also show various options and complete use of FEMWATER. Both one-dimensional (B-I) and two-dimensional (B-II, B-III, and B-IV) problems are included. Three options of providing initial conditions are demonstrated: transient simulation with prescribed initial condition (B-I), transient state computation with intial conditions obtained by steady-state solution (B-III), and steady-state solution only (B-II and B-IV). Both homogeneous and complex media can be handled. Examples B-I, B-II, and B-IV treat the media as a single homogeneous formation while example B-III considers the media as composed of two different formations.

The set up of these various options will be explained in the input data.

B-I. A SIMPLE ONE-DIMENSIONAL PROBLEM

B-I.1. Problem Description

A one-dimensional infiltration experiment was used to illustrate the operation procedure of FEMWATER. The soil column is assumed to be 160 cm long and 5 x 5 cm in cross section. The column is filled with loam soil having an initial moisture content of 0.2 cm^3/cm^3. The column is assumed to be infiltrated and maintained at a constant head on its top with a slug of water. The total infiltration occurs in 17.5 h. The problem being addressed is to find out the distributions of the pressure, moisture content, and flow velocity along the column with the passage of time. The soil properties of the loam soil are given in Figs. B-1 and B-2. For this demonstration, a total of 8.5 h simulation time was made. The initial condition was assumed to be the input rather than obtained by steady-state solution. The boundary conditions are: (1) a prescribed head of -14.49 cm is imposed on the top and (2) a zero flux is applied to the bottom.

For FEMWATER execution, the column is discretized by 25 elements and 52 nodes as shown in Fig. B-3. To minimize the bandwidth of the coefficient matrix, the nodes are numbered to proceed most rapidly along the direction that contains the least number of nodes. A constant time step of 0.1 h was used resulting in a total number of 85 time steps.

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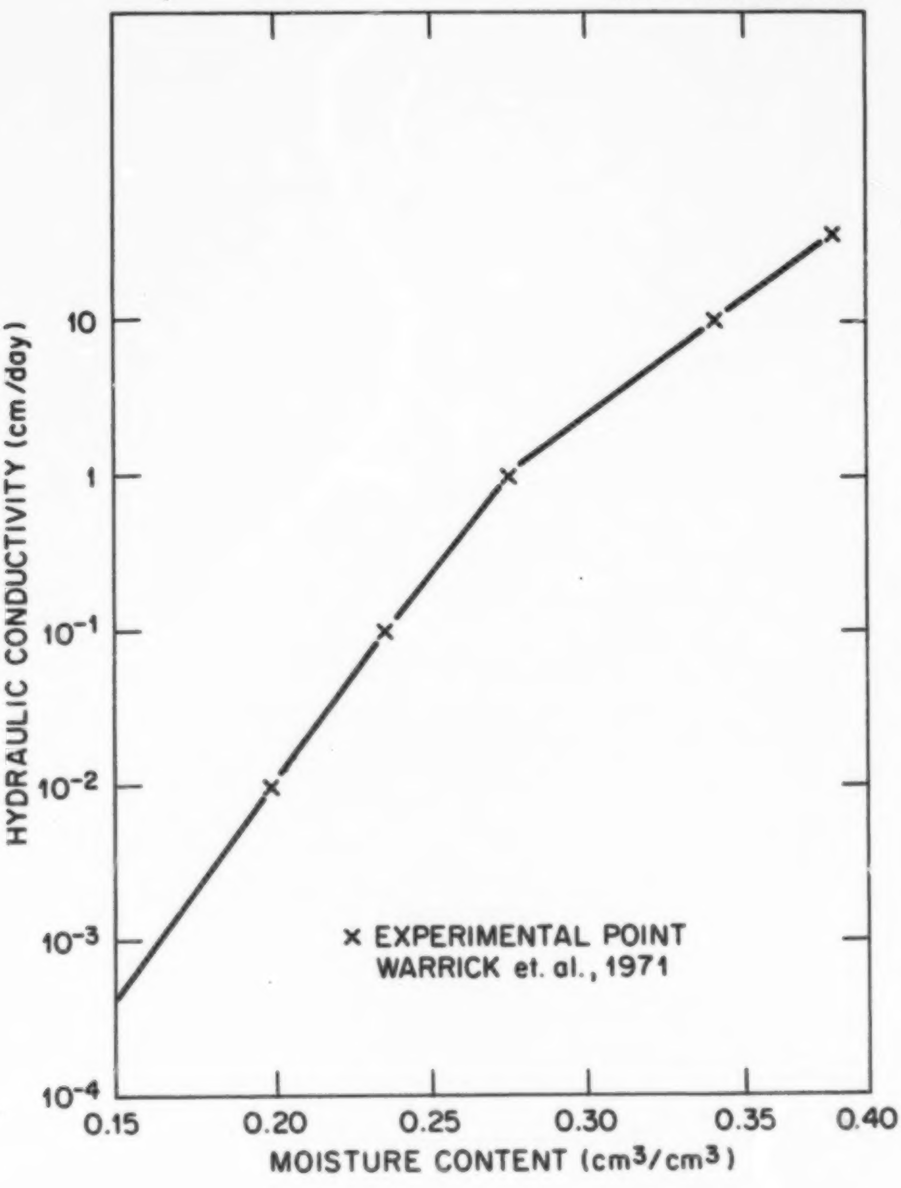

Fig. B-1. Hydraulic conductivity vs moisture content used for the simple one-dimensional problem

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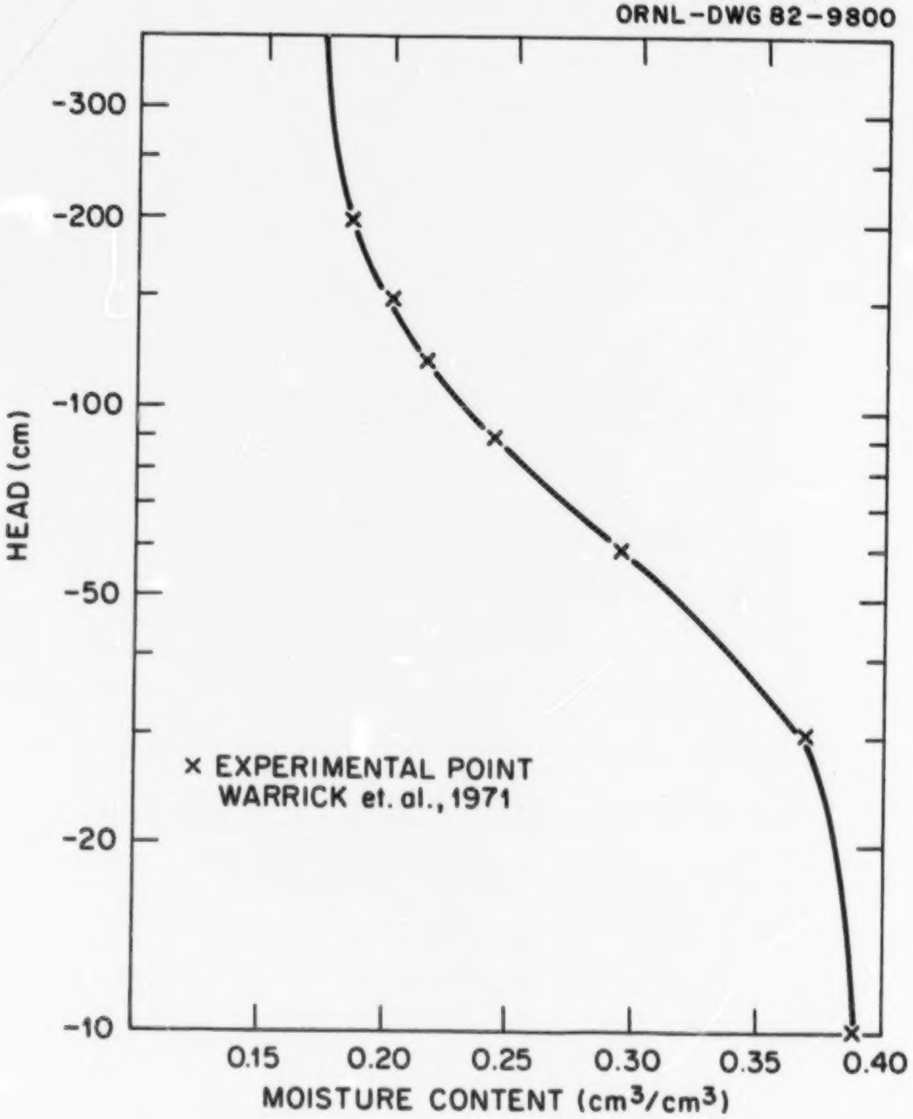

Fig. B-2. Pressure head vs moisture content used for the simple one-dimensional problem

ORNL-DWG 82-8427

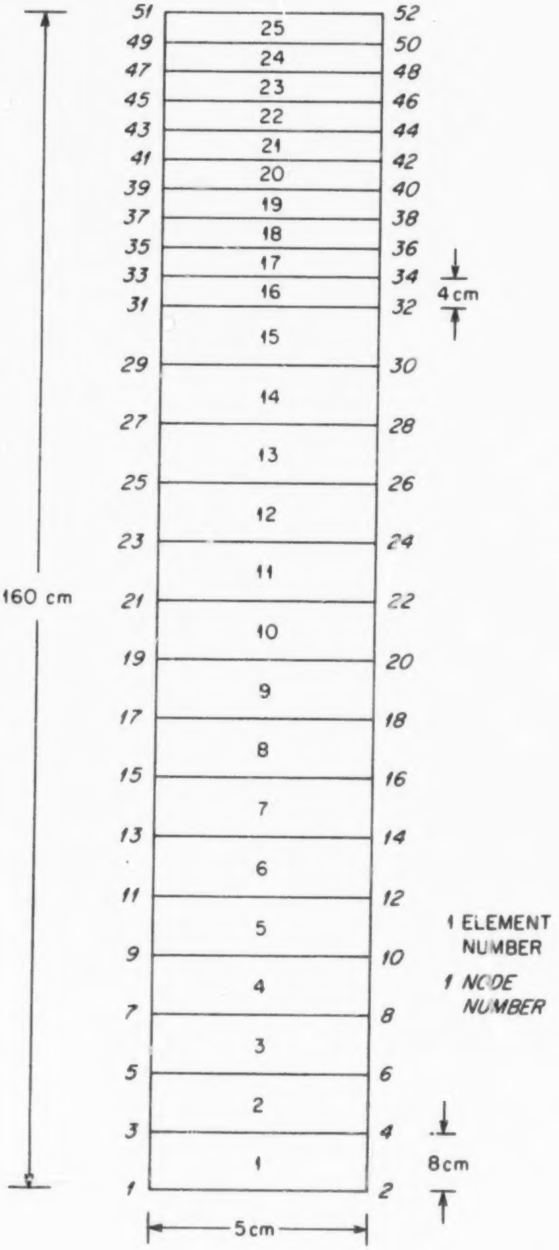
160 cm
4 cm
8cm
5cm
1 ELEMENT NUMBER
1 NODE NUMBER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

Fig. B-3. Finite element discretization for the simple one-dimensional problem

B-I.2. Input Deck

Input data and set for this simple one-dimensional problem is given in Table B.1, coded according to the instruction given in Section A-V.3. Cards with a "C" on the first column are used to explain the data immediately following. They must be removed for execution of the program. Because the initial condition is prescribed, KSS is set equal to 1. Eighty-five (85) time steps are desired to yield a total simulation of 8.5 h, NTI = 85. The media is a single homogeneous formation, thus NMAT = 1, and NCM = 0.

B-II. A SEEPAGE POND PROBLEM

B-II-1. Problem Description

A seepage pond near a stream is assumed to be situated entirely in the unsaturated zone above the water table. This pond provides the source of water which drains into the aquifer. Although the rainfall on the soil surface also provides water sources in the form of infiltration, it is on the average very small compared to the continuous drainage from the pond. After the water reaches the water table, it flows toward a nearby stream as depicted in Fig. B-4 which also outlines the surface topography and the extent of the aquifer system. This example typifies a class of problems involving leaching of wastes from storage lagoons. The soil properties are given in Fig. B-5. The problem being addressed is to find the spatial distribution of pressure head, total head, moisture content, and Darcy's velocity under the steady state condition achieved by a constant drainage rate of 1.44 cm/h. To use the FEMWATER program for

Table B.1. Input data for a simple one-dimensional problem

```
C
C ------- DATA SET 1: TITLE
   1  ONE-DIMENSIONAL SIMULATION OF WARICK'S EXPERIMENT WITH FEMWATER
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  52   25    1    0   85    1    1   24    1    0    1    0   10    2    5
   0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
 360.0      1.0        360.0      32400.0   0.0        0.11       0.01       1.0
 980.0      0.013      1.0
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
551       151       151       151       151       151       151       151       1
51  15
11111111111111111111111111111111111111111111111111111111111111111111111111111111
111111
C
C ------- DATA SET 5: MATERIAL PROPERTIES
 0.0        0.0        0.38       0.00E00   4.37E-4
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -269.11    -242.29    -218.14    -196.39    -176.82    -159.18    -143.33    -128.00
 -116.18    -104.60    -94.17     -84.79     -76.33     -68.73     -61.98     -55.71
 -50.15     -45.16     -41.13     -36.56     -32.95     -29.67     -20.90     -14.49
C ------- MOISTURE CONTENT
 0.15       0.16       0.17       0.18       0.19       0.20       0.21       0.22
 0.23       0.24       0.25       0.26       0.27       0.28       0.29       0.30
 0.31       0.32       0.33       0.34       0.35       0.36       0.37       0.38
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
   1.06E-5    2.01E-5    3.81E-5    7.28E-5    1.38E-4    2.65E-4    5.08E-4    9.73E-4
   1.88E-3    3.58E-3    6.22E-3    1.08E-2    1.89E-2    3.28E-2    4.65E-2    6.60E-2
   9.35E-2    1.32E-1    1.87E-1    2.65E-1    3.71E-1    5.20E-1    7.15E-1    1.00E00
 0.0          3.93E-4    4.36E-4    4.85E-4    5.39E-4    5.98E-4    6.61E-4    7.44E-4
   8.20E-4    9.10E-4    1.01E-3    1.12E-3    1.25E-3    1.39E-3    1.54E-3    1.54E-3
   1.90E-3    2.11E-3    2.32E-3    2.60E-3    2.90E-3    1.46E-3    1.34E-3    0.00E00
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
     1  0.0          0.0
     2  5.0          0.0
     3  0.0          8.0
     4  5.0          8.0
     5  0.0         16.0
     6  5.0         16.0
     7  0.0         24.0
     8  5.0         24.0
     9  0.0         32.0
    10  5.0         32.0
    11  0.0         40.0
    12  5.0         40.0
    13  0.0         48.0
    14  5.0         48.0
    15  0.0         56.0
    16  5.0         56.0
    17  0.0         64.0
    18  5.0         64.0
    19  0.0         72.0
    20  5.0         72.0
    21  0.0         80.0
    22  5.0         80.0
    23  0.0         88.0
    24  5.0         88.0
    25  0.0         96.0
    26  5.0         96.0
    27  0.0        104.0
    28  5.0        104.0
    29  0.0        112.0
    30  5.0        112.0
    31  0.0        120.0
    32  5.0        120.0
    33  0.0        124.0
    34  5.0        124.0
    35  0.0        128.0
    36  5.0        128.0
    37  0.0        132.0
    38  5.0        132.0
    39  0.0        136.0
    40  5.0        136.0
    41  0.0        140.0
    42  5.0        140.0
    43  0.0        144.0
    44  5.0        144.0
    45  0.0        148.0
```

Table B.1. (continued)

```
    46 5.0         148.0
    47 0.0         152.0
    48 5.0         152.0
    49 0.0         156.0
    50 5.0         156.0
    51 0.0         160.0
    52 5.0         160.0
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
    1    1    2    4    3    1    1   25
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1        -159.2
   27        -164.9
   29        -176.8
   31        -189.6
   33        -196.4
   35        -203.4
   37        -210.6
   39        -218.1
   41        -225.3
   43        -230.0
   45        -242.3
   47        -250.9
   49        -259.9
   51        -14.9
   52        -14.9
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
    2    0    0    0    0    0
C
C ------- DATA SET 13 RAINFALL PROFILES, DATA SET 14 RAINFALL TYPE AND PONDING
C ------- DEPTH, AND DATA SET 15 RAINFALL-SEEPAGE SURFACE ELEMENT SIDES ARE NOT
C ------- NEEDED SINCE NPSN=0
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
   51     0 -14.49
   52     0 -14.49
C
C ------- DATA SET 17 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18 THROUGH DATA SET 23 ARE NOT NEEDED SINCE KSS=1 AND NTI>0
C
C ------- FINIALLY A BLANK CARD TO END THE JOB
```

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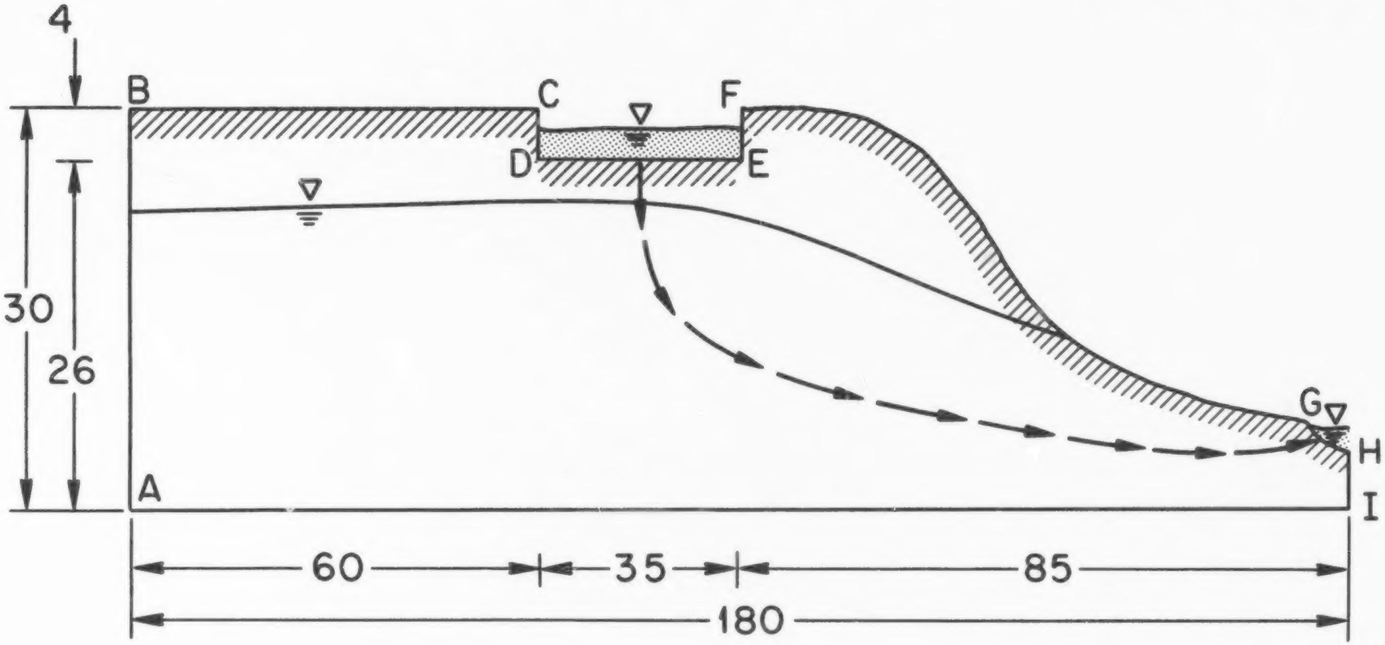
4
B
C
F
D
E
30
26
G
H
A
I
60
35
85
180

DIMENSIONS IN METERS

Fig. B-4. Sketch of the region of interest for the seepage pond problem

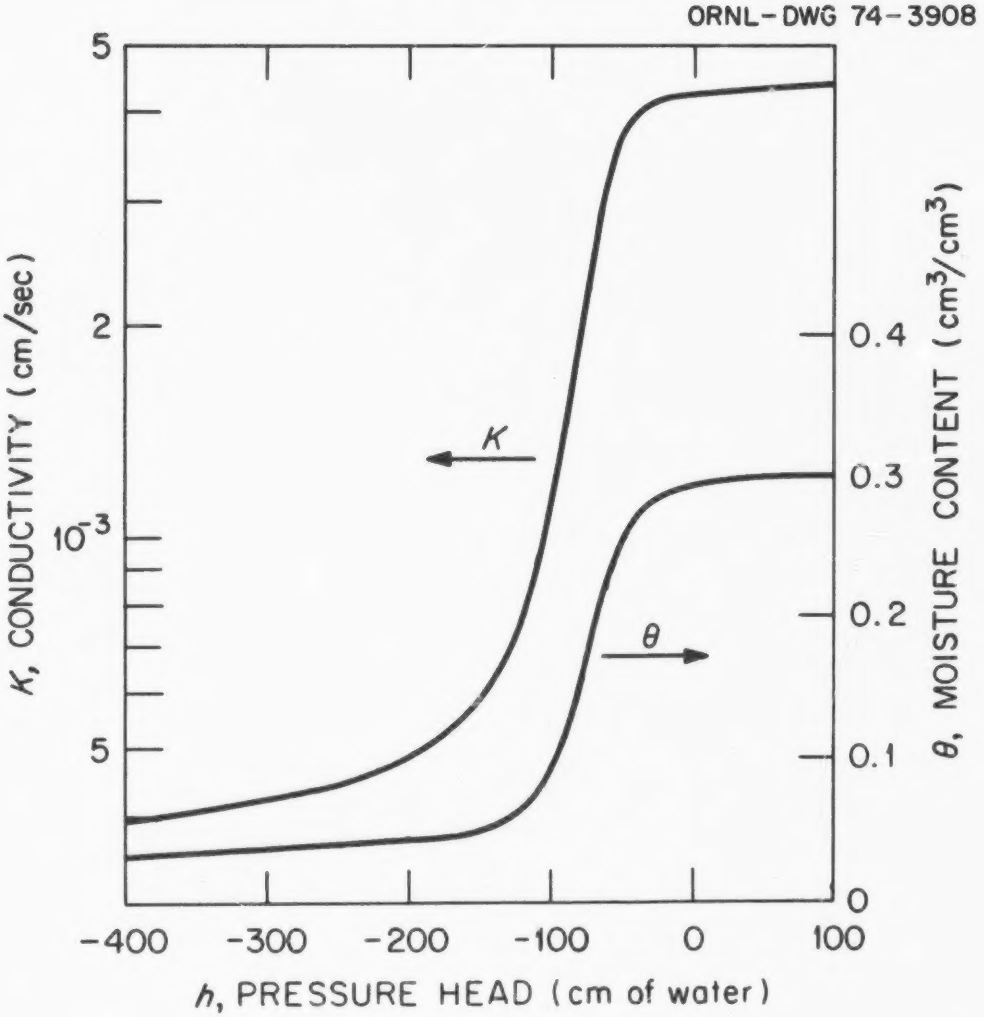

Fig. B-5. Hydraulic property functions used for the seepage pond problem answering this question, the region in Fig. B-4 is discretized by 595 nodes and 528 elements as shown in Fig. B-6. For the finite element computation, the seven nodal points on the stream-soil interface are designated as Dirichlet nodes (Fig. B-6). Seven nodal points on the bottom of the seepage pond, namely nodal point nos. 152, 164, 172, 180, 188, 196, and 204, are considered as constant Neumann flux points and are assigned a constant infiltration rate of 4.0×10^{-4} cm/s. The top sides of all elements on the sloping surface, except the two elements immediately to the right of the seepage pond, are considered the seepage-rainfall boundary surface. In other words, the nodal points on this surface are either Dirichlet or Neumann points with the infiltration rate equal to the through rainfall rate, which is assumed zero in this case. All other boundaries are treated as impervious.

B-II.2. Input Deck

With the above problem description, the input data for FEMWATER can be coded according to section A-V.3 of APPENDIX A. The complete data set is given in Table B.2. Again, cards with a "C" in column one are used for description only and must be removed for execution. The steady-state solution only is desired; thus KSS = 0 and NTI = 0. A single homogeneous media is considered, hence NMAT = 1 and NCM = 0. Also, the first three numbers on data set 3 are not used in the computation; thus they can be anything.

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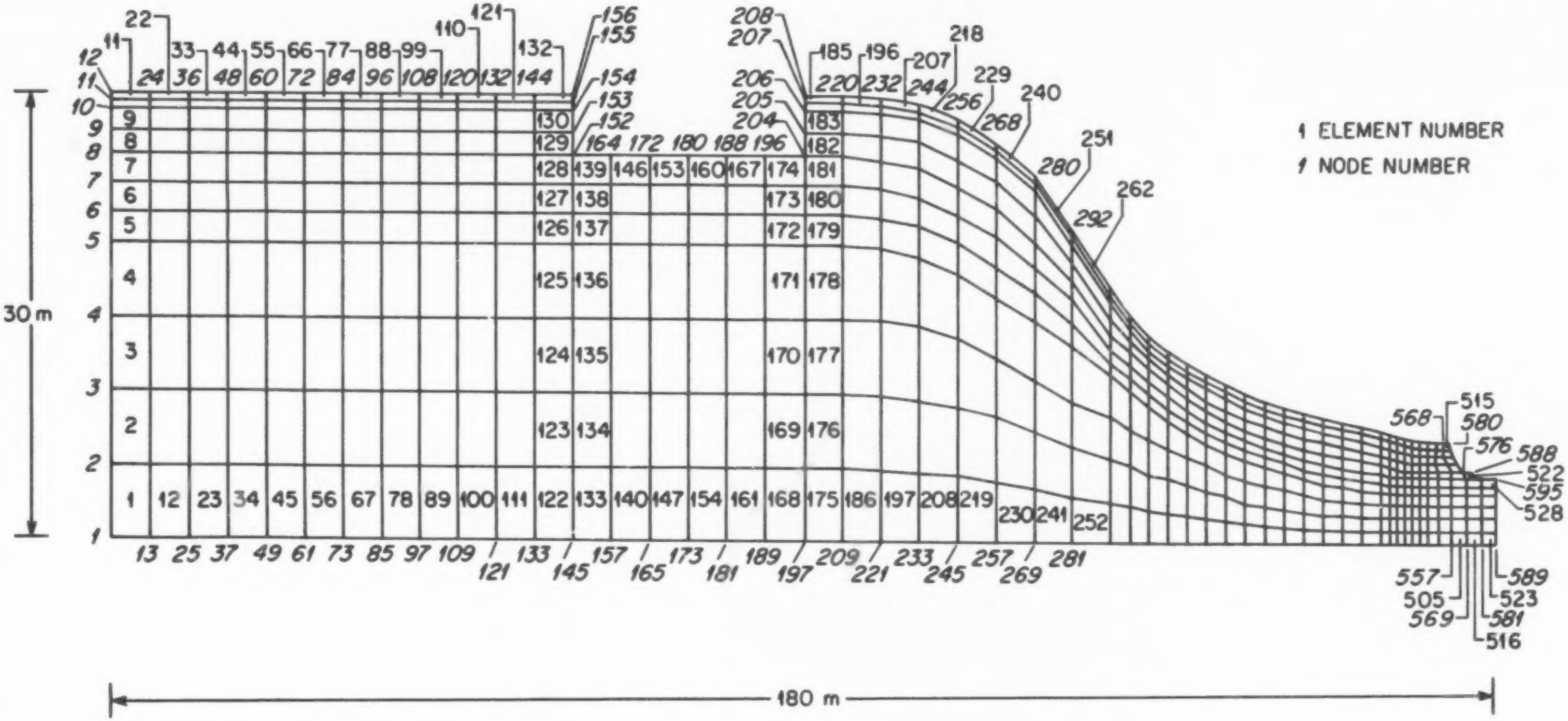

30 m
180 m
ELEMENT NUMBER
NODE NUMBER
1 2 3 4 5 6 7 8 9 10 11 12
22 33 44 55 66 77 88 99 110 121 132
24 36 48 60 72 84 96 108 120 132 144
156 155 154 153 152
164 172 180 188 196
208 207 206 205 204
185 196 207 218
220 232 244 256 268
229 240 251 262
280 292
1 2 3 4 5 6 7 8 9
12 23 34 45 56 67 78 89 100 111 122 133 140 147 154 161 168 175 186 197 208 219 230 241 252
123 124 125 126 127 128 129 130
134 135 136 137 138 139
146 153 160 167 174 181
169 170 171 172 173
176 177 178 179 180 181 182 183
13 25 37 49 61 73 85 97 109 121 133 145 157 165 173 181 189 197 209 221 233 245 257 269 281
568 515 580 576 588 522 595 528
557 505 569 589 523 581 516

Fig. B-6. Finite element discretization for the seepage pond problem

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Table B.2. Input data for a seepage pond problem

```
C
C ------- DATA SET 1: TITLE
   3     SEEPAGE POND. STEADY STATE SIMULATION. WITH FEMWATER CODE
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  595  528    1    0    0    0    1   16    1    1    1    0   20   15    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
500.        .5         86400.     0.          0.          .01         .1          1.
980.6       .013       1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55
11
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.          0.          .3                  .58E-7     .58E-7
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -800.0    -400.       -200.       -175.       -150.       -125.       -100.       -62.5
 -50.0     -37.5       -25.        -12.5       0.          50.         100.        2000.
C ------- MOISTURE CONTENT
.024        .032        .0425       .045        .050        .0625       .09         .21
.25         .275        .285        .290        .2925       .2975       .2995       .3
C ------- RELATIVE PERMEABILITY*VISCOSITY/(DENSITY*GRAVITY)
 .10057E-5 .11896E-5 .14857E-5 .16000E-5 .18286E-5 .21715E-5 .36565E-5 .91430E-5
 .10972E-4 .12114E-4 .12572E-4 .12800E-4 .12800E-4 .13029E-4 .13257E-4 .13257E-4
C ------- MOISTURE CONTENT CAPACITY
    0.          .52E-4      .10E-3      .20E-3      .50E-3      .11E-2      .32E-2      .32E-2
    .20E-2      .80E-3      .40E-3      .20E-3      .10E-3      .40E-4      .26E-6      0.
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
     1      0.0         0.0
     2      0.0       500.000
     3      0.0      1000.000
     4      0.0      1500.000
     5      0.0      2000.000
     6      0.0      2200.000
     7      0.0      2400.000
     8      0.0      2600.000
     9      0.0      2750.000
    10      0.0      2900.000
    11      0.0      2950.000
    12      0.0      3000.000
    13    500.000       0.0
    14    500.000     500.000
    15    500.000    1000.000
    16    500.000    1500.000
    17    500.000    2000.000
    18    500.000    2200.000
    19    500.000    2400.000
    20    500.000    2600.000
    21    500.000    2750.000
    22    500.000    2900.000
    23    500.000    2950.000
    24    500.000    3000.000
    25   1000.000       0.0
    26   1000.000     500.000
    27   1000.000    1000.000
    28   1000.000    1500.000
    29   1000.000    2000.000
    30   1000.000    2200.000
    31   1000.000    2400.000
    32   1000.000    2600.000
    33   1000.000    2750.000
    34   1000.000    2900.000
    35   1000.000    2950.000
    36   1000.000    3000.000
    37   1500.000       0.0
    38   1500.000     500.000
    39   1500.000    1000.000
    40   1500.000    1500.000
    41   1500.000    2000.000
    42   1500.000    2200.000
    43   1500.000    2400.000
    44   1500.000    2600.000
    45   1500.000    2750.000
    46   1500.000    2900.000
    47   1500.000    2950.000
    48   1500.000    3000.000
    49   2000.000       0.0
    50   2000.000     500.000
```

Table B.2. (continued)

51	2000.000	1000.000
52	2000.000	1500.000
53	2000.000	2000.000
54	2000.000	2200.000
55	2000.000	2400.000
56	2000.000	2600.000
57	2000.000	2750.000
58	2000.000	2900.000
59	2000.000	2950.000
60	2000.000	3000.000
61	2500.000	0.0
62	2500.000	500.000
63	2500.000	1000.00
64	2500.000	1500.000
65	2500.000	2000.000
66	2500.000	2200.000
67	2500.000	2400.000
68	2500.000	2600.000
69	2500.000	2750.000
70	2500.000	2900.000
71	2500.000	2950.000
72	2500.000	3000.000
73	3000.000	0.0
74	3000.000	500.000
75	3000.000	1000.000
76	3000.000	1500.000
77	3000.000	2000.000
78	3000.000	2200.000
79	3000.000	2400.000
80	3000.000	2600.000
81	3000.000	2750.000
82	3000.000	2900.000
83	3000.000	2950.000
84	3000.000	3000.000
85	3500.000	0.0
86	3500.000	500.000
87	3500.000	1000.000
88	3500.000	1500.000
89	3500.000	2000.000
90	3500.000	2200.000
91	3500.000	2400.000
92	3500.000	2600.000
93	3500.000	2750.000
94	3500.000	2900.000
95	3500.000	2950.000
96	3500.000	3000.000
97	4000.000	0.0
98	4000.000	500.000
99	4000.000	1000.000
100	4000.000	1500.000
101	4000.000	2000.000
102	4000.000	2200.000
103	4000.000	2400.000
104	4000.000	2600.000
105	4000.000	2750.000
106	4000.000	2900.000
107	4000.000	2950.000
108	4000.000	3000.000
109	4500.000	0.0
110	4500.000	500.000
111	4500.000	1000.000
112	4500.000	1500.000
113	4500.000	2000.000
114	4500.000	2200.000
115	4500.000	2400.000
116	4500.000	2600.000
117	4500.000	2750.000
118	4500.000	2900.000
119	4500.000	2950.000
120	4500.000	3000.000
121	5000.000	0.0
122	5000.000	500.000
123	5000.000	1000.000
124	5000.000	1500.000
125	5000.000	2000.000
126	5000.000	2200.000
127	5000.000	2400.000
128	5000.000	2600.000
129	5000.000	2750.000
130	5000.000	2900.000
131	5000.000	2950.000
132	5000.000	3000.000
133	5500.000	0.0
134	5500.000	500.000
135	5500.000	1000.000
136	5500.000	1500.000

Table B.2. (continued)

137	5500.000	2000.000
138	5500.000	2200.000
139	5500.000	2400.000
140	5500.000	2600.000
141	5500.000	2750.000
142	5500.000	2900.000
143	5500.000	2950.000
144	5500.000	3000.000
145	6000.000	0.0
146	6000.000	500.000
147	6000.000	1000.000
148	6000.000	1500.000
149	6000.000	2000.000
150	6000.000	2200.000
151	6000.000	2400.000
152	6000.000	2600.000
153	6000.000	2750.000
154	6000.000	2900.000
155	6000.000	2950.000
156	6000.000	3000.000
157	6500.000	0.0
158	6500.000	500.000
159	6500.000	1000.000
160	6500.000	1500.000
161	6500.000	2000.000
162	6500.000	2200.000
163	6500.000	2400.000
164	6500.000	2600.000
165	7000.000	0.0
166	7000.000	500.000
167	7000.000	1000.000
168	7000.000	1500.000
169	7000.000	2000.000
170	7000.000	2200.000
171	7000.000	2400.000
172	7000.000	2600.000
173	7500.000	0.0
174	7500.000	500.000
175	7500.000	1000.000
176	7500.000	1500.000
177	7500.000	2000.000
178	7500.000	2200.000
179	7500.000	2400.000
180	7500.000	2600.000
181	8000.000	0.0
182	8000.000	500.000
183	8000.000	1000.000
184	8000.000	1500.000
185	8000.000	2000.000
186	8000.000	2200.000
187	8000.000	2400.000
188	8000.000	2600.000
189	8500.000	0.0
190	8500.000	500.000
191	8500.000	1000.000
192	8500.000	1500.000
193	8500.000	2000.000
194	8500.000	2200.000
195	8500.000	2400.000
196	8500.000	2600.000
197	9000.000	0.0
198	9000.000	500.000
199	9000.000	1000.000
200	9000.000	1500.000
201	9000.000	2000.000
202	9000.000	2200.000
203	9000.000	2400.000
204	9000.000	2600.000
205	9000.000	2750.000
206	9000.000	2900.000
207	9000.000	2950.000
208	9000.000	3000.000
209	9500.000	0.0
210	9500.000	500.000
211	9500.000	1000.000
212	9500.000	1500.000
213	9500.000	2000.000
214	9500.000	2200.000
215	9500.000	2400.000
216	9500.000	2600.000
217	9500.000	2750.000
218	9500.000	2900.000
219	9500.000	2950.000
220	9500.000	3000.000
221	10000.000	0.0
222	10000.000	480.000

Table B.2. (continued)

223	10000.000	990.000
224	10000.000	1500.000
225	10000.000	1979.999
226	10000.000	2179.999
227	10000.000	2379.999
228	10000.000	2559.999
229	10000.000	2739.999
230	10000.000	2889.999
231	10000.000	2939.999
232	10000.000	2989.999
233	10500.000	0.0
234	10500.000	460.000
235	10500.000	960.000
236	10500.000	1460.000
237	10500.000	1920.000
238	10500.000	2129.999
239	10500.000	2320.000
240	10500.000	2520.000
241	10500.000	2700.000
242	10500.000	2850.000
243	10500.000	2900.000
244	10500.000	2950.000
245	11000.000	0.0
246	11000.000	450.000
247	11000.000	910.000
248	11000.000	1380.000
249	11000.000	1809.999
250	11000.000	2020.000
251	11000.000	2200.000
252	11000.000	2389.999
253	11000.000	2570.000
254	11000.000	2750.000
255	11000.000	2900.000
256	11000.000	2850.000
257	11500.000	0.0
258	11500.000	400.000
259	11500.000	850.000
260	11500.000	1250.000
261	11500.000	1659.999
262	11500.000	1859.999
263	11500.000	2059.999
264	11500.000	2250.000
265	11500.000	2439.999
266	11500.000	2599.999
267	11500.000	2639.999
268	11500.000	2689.999
269	12000.000	0.0
270	12000.000	360.000
271	12000.000	750.000
272	12000.000	1100.000
273	12000.000	1500.000
274	12000.000	1700.000
275	12000.000	1859.999
276	12000.000	2020.000
277	12000.000	2200.000
278	12000.000	2370.000
279	12000.000	2420.000
280	12000.000	2470.000
281	12500.000	0.0
282	12500.000	300.000
283	12500.000	650.000
284	12500.000	950.000
285	12500.000	1330.000
286	12500.000	1490.000
287	12500.000	1639.999
288	12500.000	1759.999
289	12500.000	1879.999
290	12500.000	2000.000
291	12500.000	2050.000
292	12500.000	2100.000
293	13000.000	0.0
294	13000.000	270.000
295	13000.000	570.000
296	13000.000	850.000
297	13000.000	1140.000
298	13000.000	1210.000
299	13000.000	1300.000
300	13000.000	1400.000
301	13000.000	1510.000
302	13000.000	1620.000
303	13000.000	1670.000
304	13000.000	1720.000
305	13250.000	0.0
306	13250.000	250.000
307	13250.000	530.000
308	13250.000	770.000

Table B.2. (continued)

309	13250.000	1030.000
310	13250.000	1120.000
311	13250.000	1200.000
312	13250.000	1300.000
313	13250.000	1370.000
314	13250.000	1450.000
315	13250.000	1500.000
316	13250.000	1550.000
317	13500.000	0.0
318	13500.000	220.000
319	13500.000	460.000
320	13500.000	700.000
321	13500.000	920.000
322	13500.000	1010.000
323	13500.000	1100.000
324	13500.000	1180.000
325	13500.000	1250.000
326	13500.000	1300.000
327	13500.000	1350.000
328	13500.000	1400.000
329	13750.000	0.0
330	13750.000	200.000
331	13750.000	440.000
332	13750.000	650.000
333	13750.000	830.000
334	13750.000	910.000
335	13750.000	1000.000
336	13750.000	1080.000
337	13750.000	1140.000
338	13750.000	1200.000
339	13750.000	1250.000
340	13750.000	1300.000
341	14000.000	0.0
342	14000.000	190.000
343	14000.000	400.000
344	14000.000	590.000
345	14000.000	750.000
346	14000.000	830.000
347	14000.000	900.000
348	14000.000	980.000
349	14000.000	1050.000
350	14000.000	1120.000
351	14000.000	1170.000
352	14000.000	1220.000
353	14250.000	0.0
354	14250.000	170.000
355	14250.000	350.000
356	14250.000	540.000
357	14250.000	670.000
358	14250.000	750.000
359	14250.000	820.000
360	14250.000	900.000
361	14250.000	960.000
362	14250.000	1050.000
363	14250.000	1100.000
364	14250.000	1150.000
365	14500.000	0.0
366	14500.000	150.000
367	14500.000	320.000
368	14500.000	470.000
369	14500.000	610.000
370	14500.000	690.000
371	14500.000	760.000
372	14500.000	830.000
373	14500.000	900.000
374	14500.000	980.000
375	14500.000	1030.000
376	14500.000	1080.000
377	14750.000	0.0
378	14750.000	140.000
379	14750.000	270.000
380	14750.000	430.000
381	14750.000	560.000
382	14750.000	630.000
383	14750.000	700.000
384	14750.000	760.000
385	14750.000	840.000
386	14750.000	910.000
387	14750.000	960.000
388	14750.000	1010.000
389	15000.000	0.0
390	15000.000	120.000
391	15000.000	250.000
392	15000.000	390.000
393	15000.000	520.000
394	15000.000	590.000

Table B.2. (continued)

395	15000.000	650.000
396	15000.000	720.000
397	15000.000	800.000
398	15000.000	860.000
399	15000.000	910.000
400	15000.000	960.000
401	15250.000	0.0
402	15250.000	110.000
403	15250.000	230.000
404	15250.000	370.000
405	15250.000	480.000
406	15250.000	550.000
407	15250.000	610.000
408	15250.000	680.000
409	15250.000	750.000
410	15250.000	820.000
411	15250.000	870.000
412	15250.000	920.000
413	15500.000	0.0
414	15500.000	100.000
415	15500.000	210.000
416	15500.000	330.000
417	15500.000	440.000
418	15500.000	500.000
419	15500.000	560.000
420	15500.000	640.000
421	15500.000	710.000
422	15500.000	790.000
423	15500.000	840.000
424	15500.000	890.000
425	15750.000	0.0
426	15750.000	100.000
427	15750.000	200.000
428	15750.000	300.000
429	15750.000	400.000
430	15750.000	470.000
431	15750.000	540.000
432	15750.000	610.000
433	15750.000	690.000
434	15750.000	750.000
435	15750.000	800.000
436	15750.000	850.000
437	16000.000	0.0
438	16000.000	100.000
439	16000.000	200.000
440	16000.000	290.000
441	16000.000	390.000
442	16000.000	450.000
443	16000.000	510.000
444	16000.000	590.000
445	16000.000	650.000
446	16000.000	730.000
447	16000.000	780.000
448	16000.000	830.000
449	16250.000	0.0
450	16250.000	90.000
451	16250.000	190.000
452	16250.000	290.000
453	16250.000	360.000
454	16250.000	440.000
455	16250.000	490.000
456	16250.000	560.000
457	16250.000	630.000
458	16250.000	700.000
459	16250.000	750.000
460	16250.000	800.000
461	16500.000	0.0
462	16500.000	90.000
463	16500.000	180.000
464	16500.000	270.000
465	16500.000	350.000
466	16500.000	410.000
467	16500.000	480.000
468	16500.000	540.000
469	16500.000	600.000
470	16500.000	660.000
471	16500.000	710.000
472	16500.000	760.000
473	16600.000	0.0
474	16600.000	90.000
475	16600.000	190.000
476	16600.000	270.000
477	16600.000	350.000
478	16600.000	400.000
479	16600.000	460.000
480	16600.000	520.000

Table B.2. (continued)

481	16600.000	590.000
482	16600.000	650.000
483	16600.000	700.000
484	16600.000	750.000
485	16700.000	0.0
486	16700.000	90.000
487	16700.000	180.000
488	16700.000	260.000
489	16700.000	340.000
490	16700.000	400.000
491	16700.000	460.000
492	16700.000	510.000
493	16700.000	570.000
494	16700.000	640.000
495	16700.000	690.000
496	16700.000	740.000
497	16800.000	0.0
498	16800.000	90.000
499	16800.000	180.000
500	16800.000	260.000
501	16800.000	340.000
502	16800.000	400.000
503	16800.000	450.000
504	16800.000	500.000
505	16800.000	560.000
506	16800.000	620.000
507	16800.000	670.000
508	16800.000	720.000
509	16900.000	0.0
510	16900.000	90.000
511	16900.000	180.000
512	16900.000	260.000
513	16900.000	340.000
514	16900.000	390.000
515	16900.000	450.000
516	16900.000	500.000
517	16900.000	550.000
518	16900.000	610.000
519	16900.000	660.000
520	16900.000	710.000
521	17000.000	0.0
522	17000.000	90.000
523	17000.000	180.000
524	17000.000	260.000
525	17000.000	340.000
526	17000.000	390.000
527	17000.000	450.000
528	17000.000	500.000
529	17000.000	550.000
530	17000.000	600.000
531	17000.000	650.000
532	17000.000	700.000
533	17100.000	0.0
534	17100.000	90.000
535	17100.000	180.000
536	17100.000	260.000
537	17100.000	340.000
538	17100.000	390.000
539	17100.000	450.000
540	17100.000	500.000
541	17100.000	550.000
542	17100.000	600.000
543	17100.000	650.000
544	17100.000	700.000
545	17250.000	0.0
546	17250.000	90.000
547	17250.000	180.000
548	17250.000	260.000
549	17250.000	340.000
550	17250.000	390.000
551	17250.000	450.000
552	17250.000	500.000
553	17200.000	550.000
554	17200.000	600.000
555	17200.000	650.000
556	17200.000	700.000
557	17400.000	0.0
558	17400.000	90.000
559	17400.000	180.000
560	17400.000	260.000
561	17400.000	340.000
562	17400.000	390.000
563	17400.000	450.000
564	17400.000	500.000
565	17350.000	550.000

Table B.2. (continued)

```
  566 17300.000    600.000
  567 17300.000    650.000
  568 17300.000    700.000
  569 17600.000      0.0
  570 17600.000     90.000
  571 17600.000    180.000
  572 17600.000    260.000
  573 17600.000    340.000
  574 17600.000    390.000
  575 17600.000    450.000
  576 17550.000    500.000
  577 17500.000    550.000
  578 17450.000    600.000
  579 17400.000    650.000
  580 17400.000    700.000
  581 17800.000      0.0
  582 17800.000     90.000
  583 17800.000    180.000
  584 17800.000    260.000
  585 17800.000    340.000
  586 17800.000    390.000
  587 17800.000    450.000
  588 17650.000    490.000
  589 18000.000      0.0
  590 18000.000     90.000
  591 18000.000    180.000
  592 18000.000    260.000
  593 18000.000    340.000
  594 18000.000    390.000
  595 18000.000    450.000
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
    1     1    13    14     2      1    11    12
  133   145   157   158   146      1
  139   151   163   164   152      1
  140   157   165   166   158      1     7     5
  175   197   209   210   198      1    11    31
  516   569   581   582   570      1
  522   575   587   588   576      1
  523   581   589   590   582      1
  528   586   594   595   587      1
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1       0.
  595       0.
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
    7     6     0     0    29    29
C
C ------- DATA SET 13 RAINFALL PROFILES ARE NOT NEEDED SINCE NRFPR=0
C
C ------- DATA SET 14: RAINFALL TYPE AND PONDING DEPTH
  244                   0.
  580         12        0.
C
C ------- DATA SET 15: RAINFALL-SEEPGAE SURFACE ELEMENT SIDES
  218   244   256     0
  515   568   580    11
  515   579   580     0
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
  579            0.0
  578           50.0
  577          100.0
  576          150.0
  588          160.0
  587          200.0
  595          200.0
C
C ------- DATA SET 17: NEUMANN BOUNDARY CONDITIONS
  152   164     0          -4.E-4     -4.E-4
  196   204     1          -4.E-4     -4.E-4
C
C ------- DATA SET 18 THROUGH DATA 23 ARE NOT NEEDED SINCE KSS=0 AND NTI=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
```

B-III. A SOLID WASTE DISPOSAL AREA PROBLEM

B-III.1. Problem Description

A typical solid waste disposal area consists of waste trenches, trench soil cover, a clay admixture seal, and seal soil cover. The cross-section of such a typical solid waste disposal area (SWDA) is shown in Fig. B-7. For this particular example, it is assumed that the seal soil cover is about 60 cm thick, the clay admixture seal is approximately 30 cm thick, and the trench soil cover is around 63 cm thick. Under the seal, there are three waste trenches, each about 63 cm deep and 10 m wide. A stream is about 40 m down slope from the disposal area. The region used for this example and its surface topography are also sketched in Fig. B-7. The properties of both soil and clay admixture are given in Fig. B-8. A constant net rainfall of 25.344 mm/h ($7.0 \cdot 10^{-4}$ cm/s) is assumed to fall on the surface for a duration of approximately 1.97 h. The problem is to use the FEMWATER program to simulate the transient hydrodynamic variables within the region in Fig. B-1 for, say, 6.13 h. The initial condition is to be obtained by steady-state solution with a constant net rainfall of 63 cm/yr ($2.0 \cdot 10^{-6}$ cm/s) falling on the surface. The boundary conditions are: (1) a variable condition is imposed on the surface, (2) the right vertical boundary under the stream is considered a Dirichlet boundary with hydrostatic pressure, (3) all other boundaries are treated as impervious.

For the FEMWATER execution, the region is discretized by 532 nodes and 486 elements as illustrated in Fig. B-9. Both the nodes and elements are numbered vertically from the bottom to top column by

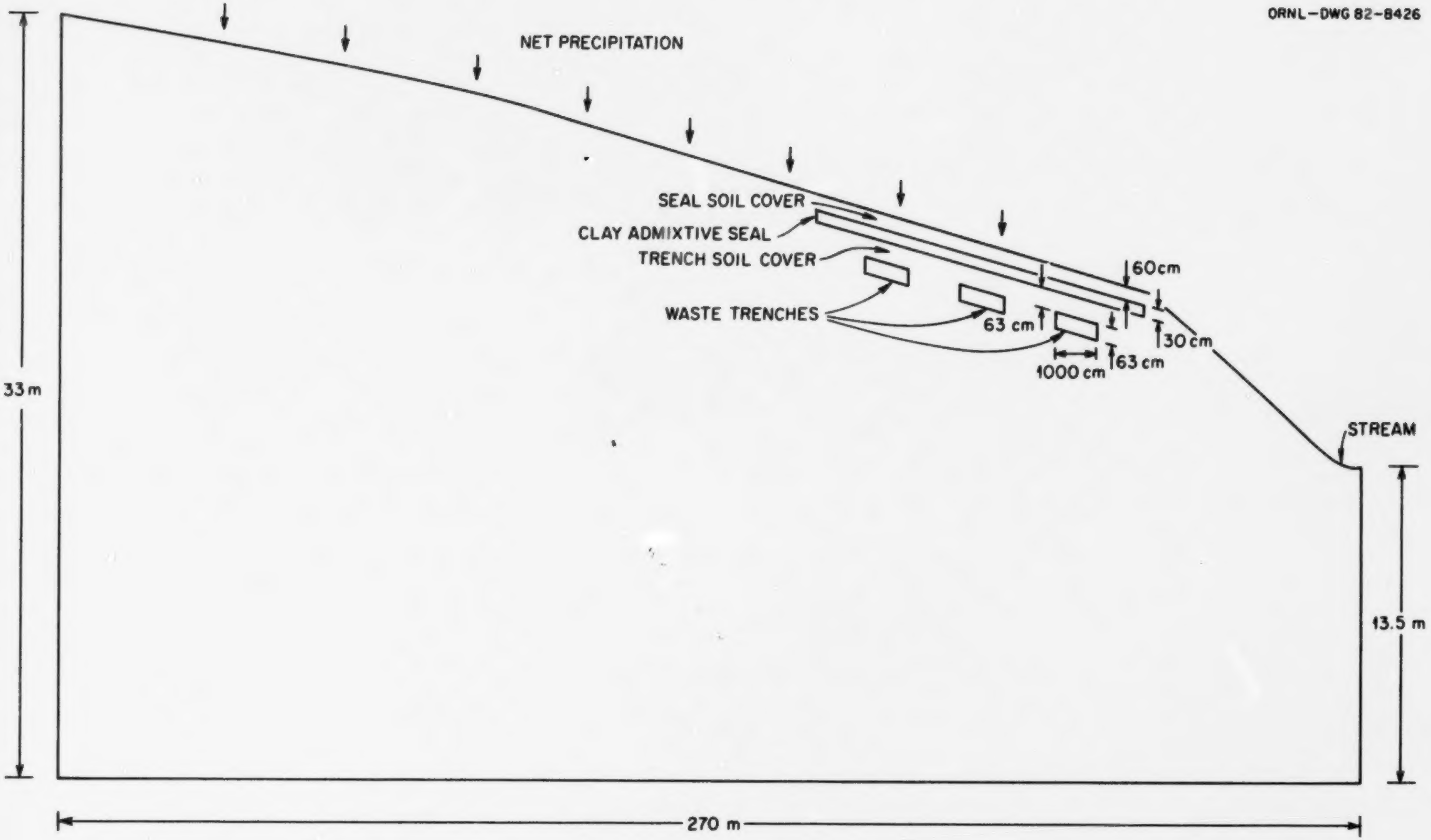
ORNL-DWG 82-8426
NET PRECIPITATION
SEAL SOIL COVER
CLAY ADMIXTIVE SEAL
TRENCH SOIL COVER
WASTE TRENCHES
60cm
63 cm
30 cm
63 cm
1000 cm
33 m
STREAM
13.5 m
270 m

Fig. B-7. Sketch of the region of interest for the solid waste disposal area problem

ORNL-DWG 82-9798

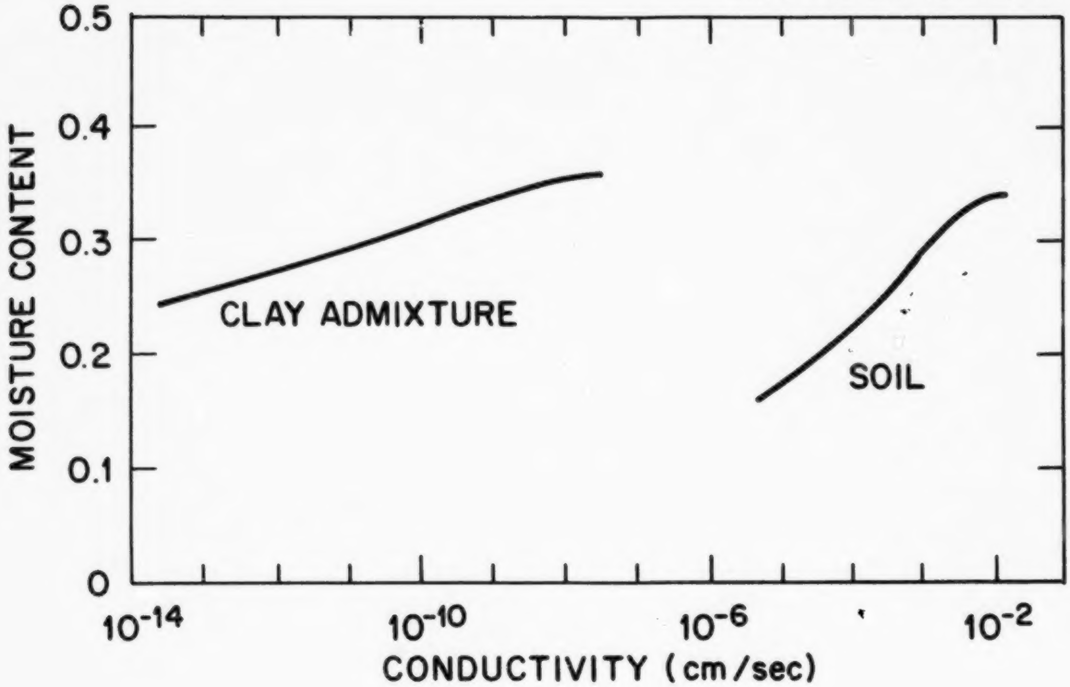

Fig. B-8. Hydraulic property functions used for the solid waste disposal area problem

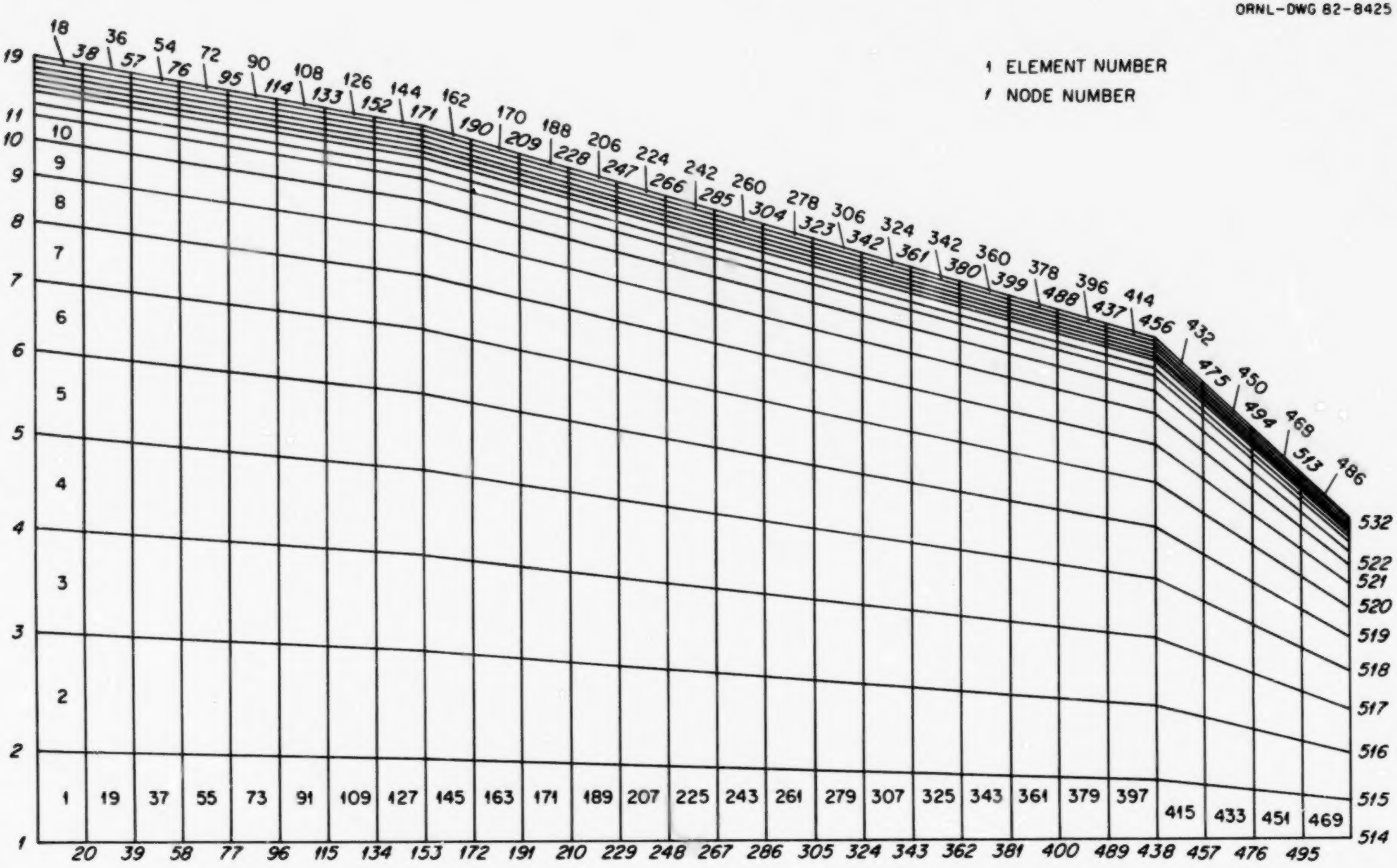
ORNL-DWG 82-8425
ELEMENT NUMBER
NODE NUMBER
18
38
36
57
54
76
72
95
90
114
108
133
126
152
144
171
162
190
170
209
188
228
206
247
224
266
242
285
260
304
278
323
306
342
324
361
342
380
360
399
378
488
396
437
414
456
432
475
450
494
468
513
486
19
11
10
9
8
7
6
5
4
3
2
1
10
9
8
7
6
5
4
3
2
1
19
37
55
73
91
109
127
145
163
171
189
207
225
243
261
279
307
325
343
361
379
397
415
433
451
469
20
39
58
77
96
115
134
153
172
191
210
229
248
267
286
305
324
343
362
381
400
489
438
457
476
495
532
522
521
520
519
518
517
516
515
514

Fig. B-9. Finite element discretization for the solid waste disposal area problem column starting with the first column on the left. This would yield the smallest bandwidth for the coefficient matrix. The initial time step is assumed to be 0.05 s. Each subsequent time step is increased by 20%. The maximum time-step size will not be greater than 5 min. With this specification, 159 time steps are required for 6.13 h real time computation.

B-III.2. Input Deck

Input data for this solid waste disposal area is given in Table B.3. Cards starting on column 1 with a "C" should not be part of the input. They are provided to explain the data. The steady state solution is used as initial condition of the subsequent transient-state computation for 159 time steps; thus KSS = 0, and NTI = 159. The media are composed of two different materials; hence NMAT = 2 and and fourteen elements (elements 301, 319, 337, 355, 373, 391, 409, 302, 338, 356, 374, 392, and 410) are to be corrected with material properties; hence NCM = 1.

Table B.3. Input data for a solid waste disposal area problem

```
C
C ------- DATA SET 1: TITLE
 1000  RESTROPECTIVE EVALUATION OF BENTONITE SEAL AT SWDA #6 WITH SEAL          11
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  532  486    2   14  159    0    1   32    1    0    1    0   30   30    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
 0.05      0.2       300.0     1000000.  0.        0.01      0.001     1.
980.6      .013      1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55111111111111111111111111111111111111111111111111511111511111111155111111111111
11111111111111111111111111111111111151111151111111111111111111111111111111111115
11                                                1     1           11
                                    1     1                                    1
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.        0.        .341      .01389    .01389
0.        0.        .364      .000001   .000001
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
-0.2570 04-0.1840 04-0.1310 04 -937.     -669.     -478.     -342.     -244.
 -174.     -124.      -88.9     -63.5     -45.4     -32.4     -23.1     -16.5
 -11.8      -8.43      -6.02     -4.30     -3.07     -2.20     -1.57     -1.12
0.        50.       100.      500.      1000.     5000.     10000.    50000.
-0.2570 04-0.1840 04-0.1310 04 -937.     -669.     -478.     -342.     -244.
 -174.     -124.      -88.9     -63.5     -45.4     -32.4     -23.1     -16.5
 -11.8      -8.43      -6.02     -4.30     -3.07     -2.20     -1.57     -1.12
0.        50.       100.      500.      1000.     5000.     10000.    50000.
C ------- MOISTURE CONTENT
 0.160     0.180     0.203     0.228     0.253     0.276     0.296     0.311
 0.322     0.329     0.334     0.337     0.338     0.340     0.340     0.340
 0.341     0.341     0.341     0.341     0.341     0.341     0.341     0.341
.34101    .34102    .34103    .34104    .34105    .34106    .34107    .34108
 0.243     0.249     0.254     0.260     0.266     0.273     0.279     0.286
 0.292     0.299     0.306     0.313     0.319     0.326     0.332     0.338
 0.343     0.348     0.352     0.355     0.357     0.359     0.360     0.361
.36401    .36402    .36403    .36404    .36405    .36406    .36406    .36407
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
 0.332D-03 0.100D-02 0.288D-02 0.777D-02 0.194D-01 0.429D-01 0.842D-01 0.145D-00
 0.222D-00 0.307D-00 0.397D-00 0.481D-00 0.599D-00 0.628D-00 0.688D-00 0.744D-00
 0.784D-00 0.820D-00 0.849D-00 0.878D-00 0.899D-00 0.914D-00 0.928D-00 0.942D-00
 0.99286   0.99353   0.99424   0.99496   0.99568   0.99640   0.99712   0.99784
 0.198D-06 0.417D-06 0.877D-06 0.185D-05 0.387D-05 0.812D-05 0.170D-04 0.355D-04
 0.738D-04 0.152D-03 0.313D-03 0.636D-03 0.128D-02 0.250D-02 0.478D-02 0.887D-02
 0.158D-01 0.271D-01 0.443D-01 0.689D-01 0.103D-00 0.145D-00 0.199D-00 0.262D-00
 0.9335    0.9427    0.9519    0.9612    0.9704    0.9797    0.9889    0.9982
C ------- MOISTURE CONTENT CAPACITY
 0.768D-04 0.124D-03 0.192D-03 0.282D-03 0.386D-03 0.482D-03 0.547D-03 0.567D-03
 0.544D-03 0.494D-03 0.432D-03 0.368D-03 0.309D-03 0.257D-03 0.212D-03 0.175D-03
 0.144D-03 0.118D-03 0.969D-04 0.795D-04 0.652D-04 0.535D-04 0.439D-04 0.360D-04
  .370E-04  .365E-04  .365E-04  .355E-04  .350E-04  .345E-04  .340E-04  .335E-04
 0.204D-04 0.294D-04 0.423D-04 0.609D-04 0.875D-04 0.126D-03 0.180D-03 0.257D-03
 0.365D-03 0.517D-03 0.727D-03 0.101D-02 0.139D-02 0.187D-02 0.247D-02 0.317D-02
 0.393D-02 0.472D-02 0.546D-02 0.611D-02 0.662D-02 0.699D-02 0.722D-02 0.734D-02
 0.734D-02 0.735D-02 0.736D-02 0.737D-02 0.738D-02 0.739D-02 0.740D-02 0.741D-02
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
    1       0.0        0.0
    2       0.0      379.5000
    3       0.0      874.5000
    4       0.0     1320.0000
    5       0.0     1716.0000
    6       0.0     2062.5000
    7       0.0     2359.5000
    8       0.0     2607.0000
    9       0.0     2805.0000
   10       0.0     2953.5000
   11       0.0     3052.5000
   12       0.0     3102.0000
   13       0.0     3151.5000
   14       0.0     3176.2500
   15       0.0     3201.0000
   16       0.0     3225.7500
   17       0.0     3250.5000
   18       0.0     3275.2500
   19       0.0     3300.0000
   20    1000.00       0.0
   21    1000.00     375.1875
   22    1000.00     864.5625
```

Table B.3. (continued)

23	1000.00	1305.0000
24	1000.00	1656.5000
25	1000.00	2039.0625
26	1000.00	2332.6875
27	1000.00	2577.3750
28	1000.00	2773.1250
29	1000.00	2919.9375
30	1000.00	3017.8125
31	1000.00	3066.7500
32	1000.00	3115.6875
33	1000.00	3140.1563
34	1000.00	3164.6250
35	1000.00	3189.0938
36	1000.00	3213.5625
37	1000.00	3238.0313
38	1000.00	3262.5000
39	2000.00	0.0
40	2000.00	370.8750
41	2000.00	854.6250
42	2000.00	1290.0000
43	2000.00	1677.0000
44	2000.00	2015.6250
45	2000.00	2305.8750
46	2000.00	2547.7500
47	2000.00	2741.2500
48	2000.00	2886.3750
49	2000.00	2983.1250
50	2000.00	3031.5000
51	2000.00	3079.8750
52	2000.00	3104.0625
53	2000.00	3128.2500
54	2000.00	3152.4375
55	2000.00	3176.6250
56	2000.00	3200.8125
57	2000.00	3225.0000
58	3000.00	0.0
59	3000.00	366.5625
60	3000.00	844.6875
61	3000.00	1275.0000
62	3000.00	1657.5000
63	3000.00	1992.1875
64	3000.00	2279.0625
65	3000.00	2518.1250
66	3000.00	2709.3750
67	3000.00	2852.8125
68	3000.00	2948.4375
69	3000.00	2996.2500
70	3000.00	3044.0625
71	3000.00	3067.9688
72	3000.00	3091.8750
73	3000.00	3115.7813
74	3000.00	3139.6875
75	3000.00	3163.5938
76	3000.00	3187.5000
77	4000.00	0.0
78	4000.00	362.2500
79	4000.00	834.7500
80	4000.00	1260.0000
81	4000.00	1638.0000
82	4000.00	1968.7500
83	4000.00	2252.2500
84	4000.00	2488.5000
85	4000.00	2677.5000
86	4000.00	2819.2500
87	4000.00	2913.7500
88	4000.00	2961.0000
89	4000.00	3008.2500
90	4000.00	3031.8750
91	4000.00	3055.5000
92	4000.00	3079.1250
93	4000.00	3102.7500
94	4000.00	3126.3750
95	4000.00	3150.0000
96	5000.00	0.0
97	5000.00	357.9375
98	5000.00	824.8125
99	5000.00	1245.0000
100	5000.00	1618.5000
101	5000.00	1945.3125
102	5000.00	2225.4375
103	5000.00	2458.8750
104	5000.00	2645.6250
105	5000.00	2785.6875
106	5000.00	2879.0625
107	5000.00	2925.7500
108	5000.00	2972.4375

Table B.3. (continued)

109	5000.00	2995.7813
110	5000.00	3019.1250
111	5000.00	3042.4688
112	5000.00	3065.8125
113	5000.00	3089.1563
114	5000.00	3112.5000
115	6000.00	0.0
116	6000.00	353.6250
117	6000.00	814.8750
118	6000.00	1230.0000
119	6000.00	1599.0000
120	6000.00	1921.8750
121	6000.00	2198.6250
122	6000.00	2429.2500
123	6000.00	2613.7500
124	6000.00	2752.1250
125	6000.00	2844.3750
126	6000.00	2890.5000
127	6000.00	2936.6250
128	6000.00	2959.6875
129	6000.00	2982.7500
130	6000.00	3005.8125
131	6000.00	3028.8750
132	6000.00	3051.9375
133	6000.00	3075.0000
134	7000.00	0.0
135	7000.00	349.3125
136	7000.00	804.9375
137	7000.00	1215.0000
138	7000.00	1579.5000
139	7000.00	1898.4375
140	7000.00	2171.8125
141	7000.00	2399.6250
142	7000.00	2581.8750
143	7000.00	2718.5625
144	7000.00	2809.6875
145	7000.00	2855.2500
146	7000.00	2900.8125
147	7000.00	2923.5938
148	7000.00	2946.3750
149	7000.00	2969.1563
150	7000.00	2991.9375
151	7000.00	3014.7188
152	7000.00	3037.5000
153	8000.00	0.0
154	8000.00	345.0000
155	8000.00	795.0000
156	8000.00	1200.0000
157	8000.00	1560.0000
158	8000.00	1875.0000
159	8000.00	2145.0000
160	8000.00	2370.0000
161	8000.00	2550.0000
162	8000.00	2685.0000
163	8000.00	2775.0000
164	8000.00	2820.0000
165	8000.00	2865.0000
166	8000.00	2887.5000
167	8000.00	2910.0000
168	8000.00	2932.5000
169	8000.00	2955.0000
170	8000.00	2977.5000
171	8000.00	3000.0000
172	9000.00	0.0
173	9000.00	338.1000
174	9000.00	779.1000
175	9000.00	1176.0000
176	9000.00	1528.8000
177	9000.00	1837.5000
178	9000.00	2102.1000
179	9000.00	2322.6000
180	9000.00	2499.0000
181	9000.00	2631.3000
182	9000.00	2719.5000
183	9000.00	2763.6000
184	9000.00	2807.7000
185	9000.00	2829.7500
186	9000.00	2851.8000
187	9000.00	2873.8500
188	9000.00	2895.9000
189	9000.00	2917.9500
190	9000.00	2940.0000
191	10000.00	0.0
192	10000.00	331.2000
193	10000.00	763.2000
194	10000.00	1152.0000

Table B.3. (continued)

195	10000.00	1497.6000
196	10000.00	1800.0000
197	10000.00	2059.2000
198	10000.00	2275.2000
199	10000.00	2448.0000
200	10000.00	2577.6000
201	10000.00	2664.0000
202	10000.00	2707.2000
203	10000.00	2750.4000
204	10000.00	2772.0000
205	10000.00	2793.6000
206	10000.00	2815.2000
207	10000.00	2836.8000
208	10000.00	2858.4000
209	10000.00	2880.0000
210	11000.00	0.0
211	11000.00	324.3000
212	11000.00	747.3000
213	11000.00	1128.0000
214	11000.00	1466.4000
215	11000.00	1762.5000
216	11000.00	2016.3000
217	11000.00	2227.8000
218	11000.00	2397.0000
219	11000.00	2523.9000
220	11000.00	2608.5000
221	11000.00	2650.8000
222	11000.00	2693.1000
223	11000.00	2714.2500
224	11000.00	2735.4000
225	11000.00	2756.5500
226	11000.00	2777.7000
227	11000.00	2798.8500
228	11000.00	2820.0000
229	12000.00	0.0
230	12000.00	317.4000
231	12000.00	731.4000
232	12000.00	1104.0000
233	12000.00	1435.2000
234	12000.00	1725.0000
235	12000.00	1973.4000
236	12000.00	2180.4000
237	12000.00	2346.0000
238	12000.00	2470.2000
239	12000.00	2553.0000
240	12000.00	2594.4000
241	12000.00	2635.8000
242	12000.00	2656.5000
243	12000.00	2677.2000
244	12000.00	2697.9000
245	12000.00	2718.6000
246	12000.00	2739.3000
247	12000.00	2760.0000
248	13000.00	0.0
249	13000.00	310.5000
250	13000.00	715.5000
251	13000.00	1080.0000
252	13000.00	1404.0000
253	13000.00	1687.5000
254	13000.00	1930.5000
255	13000.00	2133.0000
256	13000.00	2295.0000
257	13000.00	2416.5000
258	13000.00	2497.5000
259	13000.00	2538.0000
260	13000.00	2578.5000
261	13000.00	2598.7500
262	13000.00	2619.0000
263	13000.00	2639.2500
264	13000.00	2659.5000
265	13000.00	2679.7500
266	13000.00	2700.0000
267	14000.00	0.0
268	14000.00	303.6000
269	14000.00	699.6000
270	14000.00	1056.0000
271	14000.00	1372.8000
272	14000.00	1650.0000
273	14000.00	1887.6000
274	14000.00	2085.6000
275	14000.00	2244.0000
276	14000.00	2362.8000
277	14000.00	2442.0000
278	14000.00	2481.6000
279	14000.00	2521.2000
280	14000.00	2541.0000

Table B.3. (continued)

```
281   14000.00 2560.8000
282   14000.00 2580.6000
283   14000.00 2600.4000
284   14000.00 2620.2000
285   14000.00 2640.0000
286   15000.00    0.0
287   15000.00  296.7000
288   15000.00  683.7000
289   15000.00 1032.0000
290   15000.00 1341.6000
291   15000.00 1612.5000
292   15000.00 1844.7000
293   15000.00 2038.2000
294   15000.00 2193.0000
295   15000.00 2309.1000
296   15000.00 2386.5000
297   15000.00 2425.2000
298   15000.00 2463.9000
299   15000.00 2483.2500
300   15000.00 2502.6000
301   15000.00 2521.9500
302   15000.00 2541.3000
303   15000.00 2560.6500
304   15000.00 2580.0000
305   16000.00    0.0
306   16000.00  289.8000
307   16000.00  667.8000
308   16000.00 1008.0000
309   16000.00 1310.4000
310   16000.00 1575.0000
311   16000.00 1801.8000
312   16000.00 1990.8000
313   16000.00 2142.0000
314   16000.00 2255.4000
315   16000.00 2331.0000
316   16000.00 2368.8000
317   16000.00 2406.6000
318   16000.00 2425.5000
319   16000.00 2444.4000
320   16000.00 2463.3000
321   16000.00 2482.2000
322   16000.00 2501.1000
323   16000.00 2520.0000
324   17000.00    0.0
325   17000.00  282.9000
326   17000.00  651.9000
327   17000.00  984.0000
328   17000.00 1279.2000
329   17000.00 1537.5000
330   17000.00 1758.9000
331   17000.00 1943.4000
332   17000.00 2091.0000
333   17000.00 2201.7000
334   17000.00 2275.5000
335   17000.00 2312.4000
336   17000.00 2349.3000
337   17000.00 2367.7500
338   17000.00 2386.2000
339   17000.00 2404.6500
340   17000.00 2423.1000
341   17000.00 2441.5500
342   17000.00 2460.0000
343   18000.00    0.0
344   18000.00  276.0000
345   18000.00  636.0000
346   18000.00  960.0000
347   18000.00 1248.0000
348   18000.00 1500.0000
349   18000.00 1716.0000
350   18000.00 1896.0000
351   18000.00 2040.0000
352   18000.00 2148.0000
353   18000.00 2220.0000
354   18000.00 2256.0000
355   18000.00 2292.0000
356   18000.00 2310.0000
357   18000.00 2328.0000
358   18000.00 2346.0000
359   18000.00 2364.0000
360   18000.00 2382.0000
361   18000.00 2400.0000
362   19000.00    0.0
363   19000.00  269.1000
364   19000.00  620.1000
365   19000.00  936.0000
366   19000.00 1216.8000
```

Table B.3. (continued)

367	19000.00	1462.5000
368	19000.00	1673.1000
369	19000.00	1848.5000
370	19000.00	1989.0000
371	19000.00	2094.3000
372	19000.00	2164.5000
373	19000.00	2199.6000
374	19000.00	2234.7000
375	19000.00	2252.2500
376	19000.00	2269.8000
377	19000.00	2287.3500
378	19000.00	2304.9000
379	19000.00	2322.4500
380	19000.00	2340.0000
381	20000.00	0.0
382	20000.00	262.2000
383	20000.00	604.2000
384	20000.00	912.0000
385	20000.00	1185.6000
386	20000.00	1425.0000
387	20000.00	1630.2000
388	20000.00	1801.2000
389	20000.00	1938.0000
390	20000.00	2040.6000
391	20000.00	2109.0000
392	20000.00	2143.2000
393	20000.00	2177.4000
394	20000.00	2194.5000
395	20000.00	2211.6000
396	20000.00	2228.7000
397	20000.00	2245.8000
398	20000.00	2262.9000
399	20000.00	2280.0000
400	21000.00	0.0
401	21000.00	255.3000
402	21000.00	588.3000
403	21000.00	888.0000
404	21000.00	1154.4000
405	21000.00	1387.5000
406	21000.00	1587.3000
407	21000.00	1753.8000
408	21000.00	1887.0000
409	21000.00	1986.9000
410	21000.00	2053.5000
411	21000.00	2086.8000
412	21000.00	2120.1000
413	21000.00	2136.7500
414	21000.00	2153.4000
415	21000.00	2170.0500
416	21000.00	2186.7000
417	21000.00	2203.3500
418	21000.00	2220.0000
419	22000.00	0.0
420	22000.00	249.4000
421	22000.00	572.4000
422	22000.00	864.0000
423	22000.00	1123.2000
424	22000.00	1350.0000
425	22000.00	1544.4000
426	22000.00	1706.4000
427	22000.00	1836.0000
428	22000.00	1933.2000
429	22000.00	1998.0000
430	22000.00	2030.4000
431	22000.00	2062.8000
432	22000.00	2079.0000
433	22000.00	2095.2000
434	22000.00	2111.4000
435	22000.00	2127.6000
436	22000.00	2143.8000
437	22000.00	2160.0000
438	23000.00	0.0
439	23000.00	241.5000
440	23000.00	556.5000
441	23000.00	840.0000
442	23000.00	1092.0000
443	23000.00	1312.5000
444	23000.00	1501.5000
445	23000.00	1659.0000
446	23000.00	1785.0000
447	23000.00	1879.5000
448	23000.00	1942.5000
449	23000.00	1974.0000
450	23000.00	2005.5000
451	23000.00	2021.2500
452	23000.00	2037.0000

Table B.3. (continued)

```
  453   23000.00  2052.7500
  454   23000.00  2068.5000
  455   23000.00  2084.2500
  456   23000.00  2100.0000
  457   24000.00     0.0
  458   24000.00   219.9375
  459   24000.00   506.8125
  460   24000.00   765.0000
  461   24000.00   994.5000
  462   24000.00  1195.3125
  463   24000.00  1367.4375
  464   24000.00  1510.8750
  465   24000.00  1625.6250
  466   24000.00  1711.6875
  467   24000.00  1769.0625
  468   24000.00  1797.7500
  469   24000.00  1826.4375
  470   24000.00  1840.7813
  471   24000.00  1855.1250
  472   24000.00  1869.4688
  473   24000.00  1883.8125
  474   24000.00  1898.1563
  475   24000.00  1912.5000
  476   25000.00     0.0
  477   25000.00   198.3750
  478   25000.00   457.1250
  479   25000.00   690.0000
  480   25000.00   897.0000
  481   25000.00  1078.1250
  482   25000.00  1233.3750
  483   25000.00  1362.7500
  484   25000.00  1466.2500
  485   25000.00  1543.8750
  486   25000.00  1595.6250
  487   25000.00  1621.5000
  488   25000.00  1647.3750
  489   25000.00  1660.3125
  490   25000.00  1673.2500
  491   25000.00  1686.1875
  492   25000.00  1699.1250
  493   25000.00  1712.0625
  494   25000.00  1725.0000
  495   26000.00     0.0
  496   26000.00   176.8125
  497   26000.00   407.4375
  498   26000.00   615.0000
  499   26000.00   799.5000
  500   26000.00   960.9375
  501   26000.00  1099.3125
  502   26000.00  1214.6250
  503   26000.00  1306.8750
  504   26000.00  1375.0625
  505   26000.00  1422.1875
  506   26000.00  1445.2500
  507   26000.00  1468.3125
  508   26000.00  1479.8438
  509   26000.00  1491.3750
  510   26000.00  1502.9063
  511   26000.00  1514.4375
  512   26000.00  1525.9688
  513   26000.00  1537.5000
  514   27000.00     0.0
  515   27000.00   155.2500
  516   27000.00   357.7500
  517   27000.00   540.0000
  518   27000.00   702.0000
  519   27000.00   843.7500
  520   27000.00   965.2500
  521   27000.00  1066.5000
  522   27000.00  1147.5000
  523   27000.00  1208.2500
  524   27000.00  1248.7500
  525   27000.00  1269.0000
  526   27000.00  1289.2500
  527   27000.00  1299.3750
  528   27000.00  1309.5000
  529   27000.00  1319.6250
  530   27000.00  1329.7500
  531   27000.00  1339.8750
  532   27000.00  1350.0000
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
    1     1   20   21    2     1    19   27
C
C ------- DATA SET 10: MATERIAL CORRECTIONS
  301     2  409   18
```

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Table B.3. (continued)

```
  302    2  410    19
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1           0.
  532           0.
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
   19    0    1    3   26   27
C
C ------- DATA SET 13:  RAINFALL PROFILES
 0.0         999999.0  1000000.0
   2.0E-06    2.0E-06      0.0
C
C ------- DATA SET 14: RAINFALL TYPE AND PONDING DEPTH
   19    1    0        0.0
  513    1   19        0.0
C
C ------- DATA SET 15: RAINFALL-SEEPGAE SURFACE ELEMENT SIDES
   18   19   38    0
  468  494  513   18
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
  514        1350.0
  515        1194.75
  516        992.25
  517        810.0
  518        648.0
  519        506.25
  520        394.75
  521        283.5
  522        202.5
  523        141.75
  524        101.25
  525        81.0
  526        60.75
  527        50.625
  528        40.5
  529        30.375
  530        20.25
  531        10.125
  532        0.0
C
C ------- DATA SET 17  NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18:  TRANSIENT STATE INTEGER PARAMETERS
   19    0    1    5   26   27
C
C ------- DATA SET 19: RAINFALL PROFILES
 0.0          7097.700  7097.705  999999.0  1000000.0
   7.0E-04    7.0E-04 0.0         0.0         0.0
C
C ------- DATA SET 20:  RAINFALL TYPE AND PONDING DEPTH
   19    1    0        0.0
  513    1   19        0.0
C
C ------- DATA SET 21: RAINFALL-SEEPAGE SURFACE ELEMENT SIDES
   18   19   38    0
  468  494  513   18
C
C ------- DATA SET 22:  DIRICHLET BOUNDARY CONDITIONS
  514        1350.0
  515        1194.75
  516        992.25
  517        810.0
  518        648.0
  519        506.25
  520        384.75
  521        283.5
  522        202.5
  523        141.75
  524        101.25
  525        81.0
  526        60.75
  527        50.625
  528        40.5
  529        30.375
  530        20.25
  531        10.125
  532        0.0
C
C ------- DATA SET 23 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
```

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B-IV. A SHALLOW TRENCH BURIAL PROBLEM

B-IV.1. Problem Description

Low-level wastes are normally buried in trenches and are covered with the natural soil after filling. On the ground surface, artificial materials, such as asphalt or bentonite, may or may not be used for sealing purposes. A typical cross-section through the trench and its associated surface seep are shown in Fig. B-10. The trench is 3.2 m wide (only half of the width is shown because of symmetry) and 5.75 m deep, with only the lower 2.35 m filled with radioactive wastes. The transporting fluid enters the soil material (weathered shale) in the form of infiltrating precipitation, travels horizontally as well as vertically toward the water table, and eventually emanates at the downslope seep and at the stream as depicted in Fig. B-10. Disposal of solid coal wastes, chemicals, and sanitary wastes in landfills resembles this type of practice. For this sample problem, it is assumed that only the steady-state hydrodynamic variables will be desired as functions of space under the condition of averaged net rainfall being applied on the surface. To properly address this problem soil properties must be given, which are plotted in Fig. B-11. To apply FEMWATER, the region of interest is discretized into 533 nodes and 480 elements as in Fig. B-12. An averaged net rainfall rate of 77.6 cm/yr is assumed. The boundary conditions for the FEMWATER computations are specified as follows: (a) variable boundary conditions are imposed on the ground surface, (b) Dirichlet boundary conditions with zero head are implied on that portion of the

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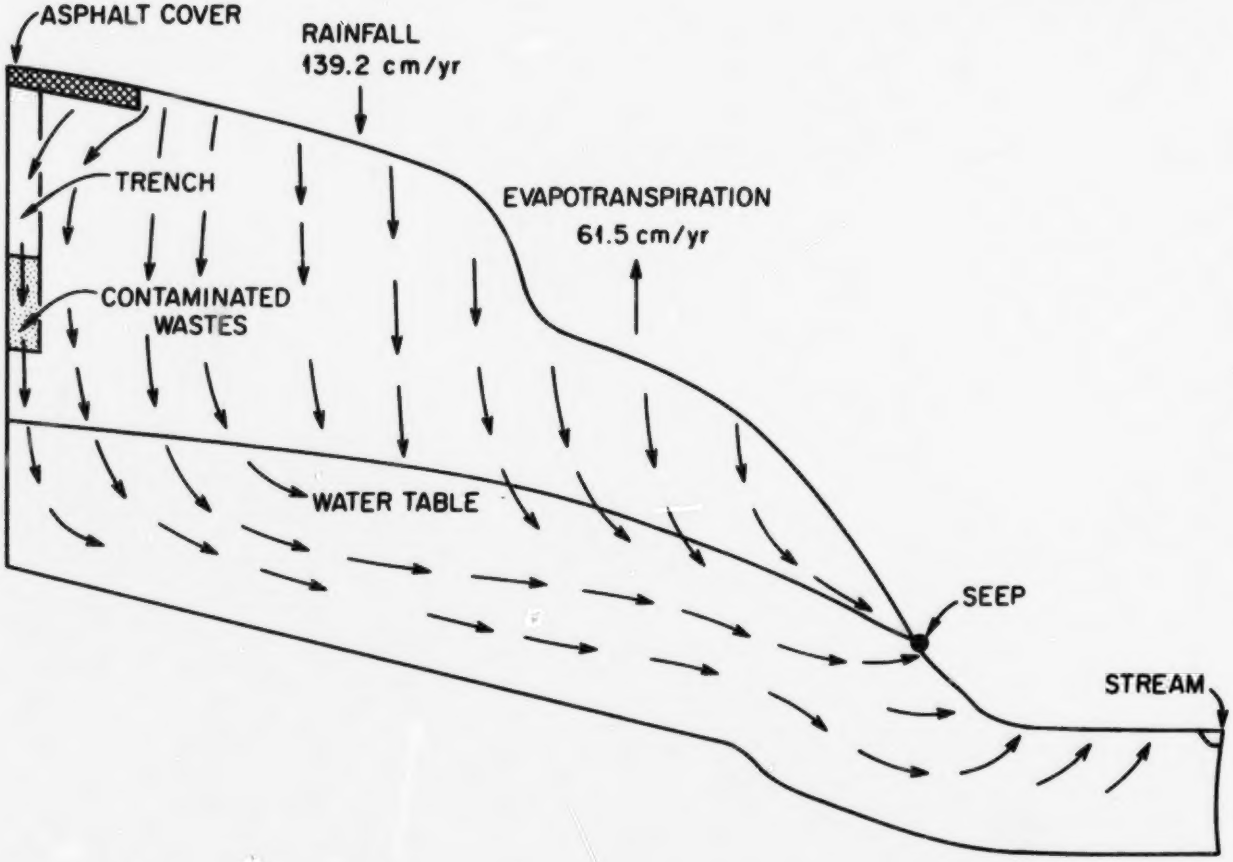
ASPHALT COVER
RAINFALL
139.2 cm/yr
TRENCH
EVAPOTRANSPIRATION
61.5 cm/yr
CONTAMINATED
WASTES
WATER TABLE
SEEP
STREAM

Fig. B-10. Sketch of the region of interest for the shallow trench burial problem

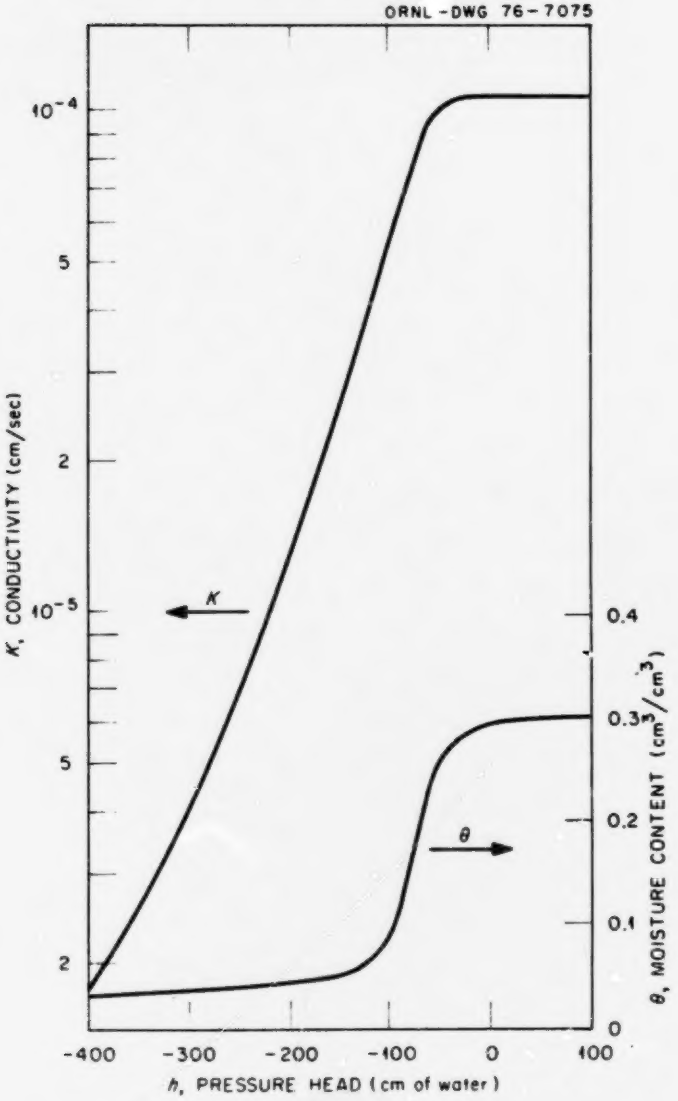

Fig. B-11. Hydraulic property functions used for the shallow trench burial problem

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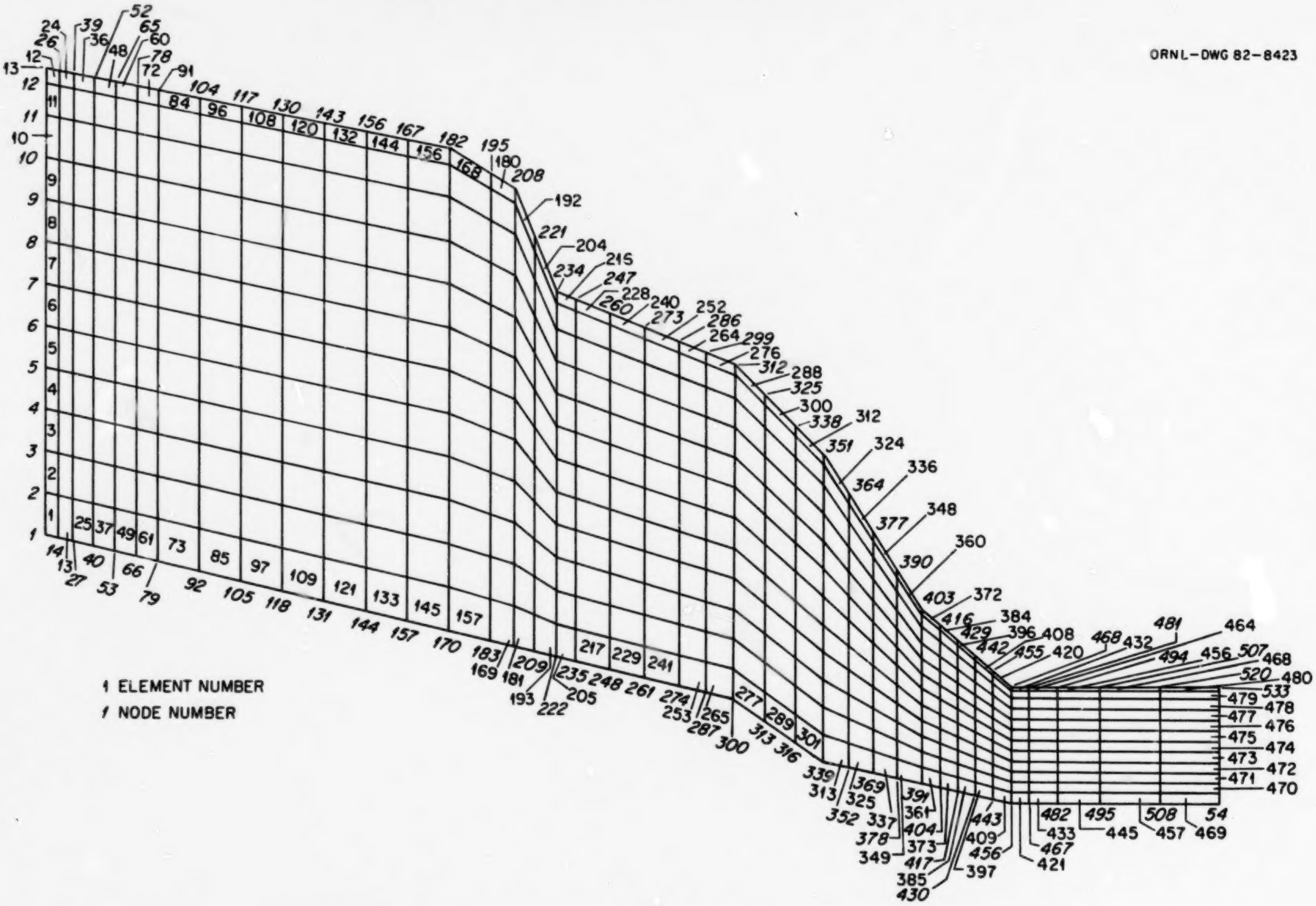
1 ELEMENT NUMBER
1 NODE NUMBER

Fig. B-12. Finite element discretization for the shallow trench problem ground surface down slope from the seep, and (c) Neumann zero-flux boundary conditions are used for all other boundaries of the region of interest.

B-IV.2. Input Deck

Following the intructions given in Section A-V.3 of APPENDIX A, one should be able to prepare an input deck similar to the one given in Table B.4. It should be noted that the first four numbers on Card Data Set 3 can be anything because only the steady-state solution is desired. Because only the steady-state solution is sought, NTI = 0 and KSS = 0. A single homogeneous material is considered; thus NMAT = 1 and NCM = 0. Again, the comment cards are for explanation and must be removed for execution.

Table B.4. Input data for a shallow trench burial problem

```
C
C ------- DATA SET 1: TITLE
   5 SHALLOW TRENCH BURIAL WATER FLOW STEADY STATE SIMULATION - FEMWATER
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  533  480    1    0    0    0    1   16    1    0    1    0  100    7    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
300.        .5          21600.0    2678400.0 0.          .01         .1          1.
980.6       .013        1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55
11
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.          0.          .3                     1.01E-4   1.01E-4
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -800.0     -400.       -200.       -175.       -150.       -125.       -100.       -62.5
 -50.0      -37.5       -25.        -12.5       0.          50.         100.        2000.
C ------- MOISTURE CONTENT
.024        .032        .0425       .045        .050        .0625       .09         .21
.25         .275        .285        .290        .2925       .2975       .2995       .3
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
 0.015       0.018       0.103       0.190       0.280       0.420       0.500       0.98
 1.0         1.01        1.01        1.01        1.01        1.01        1.01        1.01
C ------- MOISTURE CONTENT CAPACITY
    0.          .52E-4      .10E-3      .20E-3      .50E-3      .11E-2      .32E-2      .32E-2
    .20E-2      .80E-3      .40E-3      .20E-3      .10E-3      .40E-4      .26E-6      0.
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
     1       0.0        600.000
     2       0.0        697.200
     3       0.0        794.400
     4       0.0        891.600
     5       0.0        988.800
     6       0.0       1086.000
     7       0.0       1183.200
     8       0.0       1280.400
     9       0.0       1377.600
    10       0.0       1474.800
    11       0.0       1572.000
    12       0.0       1644.000
    13       0.0       1680.000
    14      80.000      592.700
    15      80.000      690.003
    16      80.000      787.306
    17      80.000      884.609
    18      80.000      981.913
    19      80.000     1079.216
    20      80.000     1176.519
    21      80.000     1273.822
    22      80.000     1371.125
    23      80.000     1468.428
    24      80.000     1565.732
    25      80.000     1637.808
    26      80.0       1673.846
    27     160.000      585.400
    28     160.000      682.806
    29     160.000      780.213
    30     160.000      877.619
    31     160.000      975.025
    32     160.000     1072.432
    33     160.000     1169.838
    34     160.000     1267.244
    35     160.000     1364.650
    36     160.000     1462.057
    37     160.000     1559.463
    38     160.000     1631.616
    39     160.0       1667.692
    40     285.000      573.994
    41     285.000      671.561
    42     285.000      769.129
    43     285.000      866.696
    44     285.000      964.264
    45     285.000     1061.831
    46     285.000     1159.399
    47     285.000     1256.966
    48     285.000     1354.534
    49     285.000     1452.101
    50     285.000     1549.669
```

Table B.4. (continued)

```
 51    285.000   1621.941
 52    285.0     1658.077
 53    410.000    562.588
 54    410.000    660.316
 55    410.000    758.045
 56    410.000    855.773
 57    410.000    953.502
 58    410.000   1051.231
 59    410.000   1148.959
 60    410.000   1246.688
 61    410.000   1344.417
 62    410.000   1442.145
 63    410.000   1539.874
 64    410.000   1612.266
 65    410.0     1648.462
 66    535.000    551.181
 67    535.000    649.071
 68    535.000    746.961
 69    535.000    844.851
 70    535.000    942.741
 71    535.000   1040.630
 72    535.000   1138.520
 73    535.000   1236.410
 74    535.000   1334.300
 75    535.000   1432.190
 76    535.000   1530.080
 77    535.000   1602.591
 78    535.0     1638.846
 79    660.000    539.775
 80    660.000    637.826
 81    660.000    735.877
 82    660.000    833.928
 83    660.000    931.979
 84    660.000   1030.030
 85    660.000   1128.081
 86    660.000   1226.132
 87    660.000   1324.183
 88    660.000   1422.234
 89    660.000   1520.285
 90    660.000   1592.916
 91    660.0     1629.231
 92    900.000    517.875
 93    900.000    616.235
 94    900.000    714.596
 95    900.000    812.956
 96    900.000    911.317
 97    900.000   1009.677
 98    900.000   1108.038
 99    900.000   1206.398
100    900.000   1304.759
101    900.000   1403.119
102    900.000   1501.480
103    900.000   1574.339
104    900.0     1610.769
105   1140.000    495.975
106   1140.000    594.645
107   1140.000    693.315
108   1140.000    791.985
109   1140.000    890.655
110   1140.000    989.325
111   1140.000   1087.995
112   1140.000   1186.665
113   1140.000   1285.335
114   1140.000   1384.004
115   1140.000   1482.674
116   1140.000   1555.763
117   1140.0     1592.308
118   1380.000    474.075
119   1380.000    573.054
120   1380.000    672.034
121   1380.000    771.013
122   1380.000    869.993
123   1380.000    968.972
124   1380.000   1067.951
125   1380.000   1166.931
126   1380.000   1265.910
127   1380.000   1364.890
128   1380.000   1463.869
129   1380.000   1537.187
130   1380.0     1573.846
131   1620.000    452.175
132   1620.000    551.464
133   1620.000    650.753
134   1620.000    750.042
135   1620.000    849.330
136   1620.000    948.619
```

Table B.4. (continued)

137	1620.000	1047.909
138	1620.000	1147.197
139	1620.000	1246.486
140	1620.000	1345.775
141	1620.000	1445.064
142	1620.000	1518.611
143	1620.0	1555.385
144	1860.000	430.275
145	1860.000	529.873
146	1860.000	629.472
147	1860.000	729.070
148	1860.000	828.668
149	1860.000	928.267
150	1860.000	1027.865
151	1860.000	1127.463
152	1860.000	1227.062
153	1860.000	1326.660
154	1860.000	1426.258
155	1860.000	1500.035
156	1860.0	1536.923
157	2100.000	408.375
158	2100.000	508.283
159	2100.000	608.191
160	2100.000	708.098
161	2100.000	808.006
162	2100.000	907.914
163	2100.000	1007.822
164	2100.000	1107.730
165	2100.000	1207.637
166	2100.000	1307.545
167	2100.000	1407.453
168	2100.000	1481.459
169	2100.0	1518.462
170	2340.000	386.475
171	2340.000	486.692
172	2340.000	586.909
173	2340.000	687.127
174	2340.000	787.344
175	2340.000	887.561
176	2340.000	987.778
177	2340.000	1087.996
178	2340.000	1188.213
179	2340.000	1288.430
180	2340.000	1388.648
181	2340.000	1462.883
182	2340.000	1500.000
183	2580.000	364.575
184	2580.000	461.509
185	2580.000	558.443
186	2580.000	655.378
187	2580.000	752.312
188	2580.000	849.246
189	2580.000	946.180
190	2580.000	1043.114
191	2580.000	1140.049
192	2580.000	1236.983
193	2580.000	1333.917
194	2580.000	1405.720
195	2580.000	1441.622
196	2710.000	352.712
197	2710.000	447.868
198	2710.000	543.024
199	2710.000	638.180
200	2710.000	733.336
201	2710.000	828.492
202	2710.000	923.648
203	2710.000	1018.804
204	2710.000	1113.960
205	2710.000	1209.115
206	2710.000	1304.271
207	2710.000	1374.757
208	2710.000	1410.009
209	2835.000	341.306
210	2835.000	426.914
211	2835.000	512.521
212	2835.000	598.129
213	2835.000	683.736
214	2835.000	769.343
215	2835.000	854.951
216	2835.000	940.558
217	2835.000	1026.165
218	2835.000	1111.773
219	2835.000	1197.381
220	2835.000	1260.794
221	2835.000	1292.500
222	2960.000	329.900

Table B.4. (continued)

223	2960.000	405.959
224	2960.000	482.018
225	2960.000	558.077
226	2960.000	634.136
227	2960.000	710.195
228	2960.000	786.254
229	2960.000	862.313
230	2960.000	938.372
231	2960.000	1014.431
232	2960.000	1090.490
233	2960.000	1146.830
234	2960.000	1175.000
235	3080.000	318.950
236	3080.000	394.281
237	3080.000	469.612
238	3080.000	544.943
239	3080.000	620.274
240	3080.000	695.605
241	3080.000	770.936
242	3080.000	846.267
243	3080.000	921.598
244	3080.000	996.929
245	3080.000	1072.260
246	3080.000	1128.061
247	3080.000	1155.962
248	3280.000	300.700
249	3280.000	374.818
250	3280.000	448.936
251	3280.000	523.053
252	3280.000	597.171
253	3280.000	671.289
254	3280.000	745.407
255	3280.000	819.524
256	3280.000	893.642
257	3280.000	967.760
258	3280.000	1041.878
259	3280.000	1096.780
260	3280.000	1124.231
261	3480.000	282.450
262	3480.000	355.355
263	3480.000	428.259
264	3480.000	501.164
265	3480.000	574.069
266	3480.000	646.973
267	3480.000	719.877
268	3480.000	792.782
269	3480.000	865.686
270	3480.000	938.591
271	3480.000	1011.495
272	3480.000	1065.498
273	3480.000	1092.500
274	3680.000	264.200
275	3680.000	335.891
276	3680.000	407.582
277	3680.000	479.274
278	3680.000	550.965
279	3680.000	622.656
280	3680.000	694.347
281	3680.000	766.039
282	3680.000	837.730
283	3680.000	909.421
284	3680.000	981.112
285	3680.000	1034.217
286	3680.000	1060.769
287	3840.000	249.600
288	3840.000	320.321
289	3840.000	391.041
290	3840.000	461.762
291	3840.000	532.482
292	3840.000	603.203
293	3840.000	673.924
294	3840.000	744.644
295	3840.000	815.365
296	3840.000	886.086
297	3840.000	956.806
298	3840.000	1009.192
299	3840.000	1035.385
300	4000.000	235.000
301	4000.000	304.750
302	4000.000	374.500
303	4000.000	444.250
304	4000.000	514.000
305	4000.000	583.750
306	4000.000	653.500
307	4000.000	723.250
308	4000.000	793.000

Table B.4. (continued)

309	4000.000	862.750
310	4000.000	932.500
311	4000.000	984.167
312	4000.000	1010.000
313	4175.000	186.667
314	4175.000	254.317
315	4175.000	321.967
316	4175.000	389.617
317	4175.000	457.267
318	4175.000	524.917
319	4175.000	592.567
320	4175.000	660.217
321	4175.000	727.867
322	4175.000	795.517
323	4175.000	863.167
324	4175.000	913.278
325	4175.000	938.333
326	4350.000	138.333
327	4350.000	203.883
328	4350.000	269.433
329	4350.000	334.983
330	4350.000	400.533
331	4350.000	466.083
332	4350.000	531.633
333	4350.000	597.183
334	4350.000	662.733
335	4350.000	728.283
336	4350.000	793.833
337	4350.000	842.389
338	4350.0	866.667
339	4525.000	90.000
340	4525.000	153.450
341	4525.000	216.900
342	4525.000	280.350
343	4525.000	343.800
344	4525.000	407.250
345	4525.000	470.700
346	4525.000	534.150
347	4525.000	597.600
348	4525.000	661.050
349	4525.000	724.500
350	4525.000	771.500
351	4525.000	795.000
352	4665.000	78.387
353	4665.000	135.120
354	4665.000	191.852
355	4665.000	248.585
356	4665.000	305.318
357	4665.000	362.050
358	4665.000	418.783
359	4665.000	475.516
360	4665.000	532.248
361	4665.000	588.981
362	4665.000	645.714
363	4665.000	687.738
364	4665.000	708.750
365	4805.000	66.774
366	4805.000	116.790
367	4805.000	166.805
368	4805.000	216.820
369	4805.000	266.835
370	4805.000	316.851
371	4805.000	366.866
372	4805.000	416.881
373	4805.000	466.897
374	4805.000	516.912
375	4805.000	566.927
376	4805.000	603.976
377	4805.000	622.500
378	4945.000	55.161
379	4945.000	98.459
380	4945.000	141.757
381	4945.000	185.055
382	4945.000	228.353
383	4945.000	271.651
384	4945.000	314.949
385	4945.000	358.247
386	4945.000	401.545
387	4945.000	444.843
388	4945.000	488.141
389	4945.000	520.214
390	4945.000	536.250
391	5085.000	43.545
392	5085.000	80.129
393	5085.000	116.710
394	5085.000	153.290

Table B.4. (continued)

395	5085.000	189.871
396	5085.000	226.452
397	5085.000	263.032
398	5085.000	299.613
399	5085.000	336.194
400	5085.000	372.774
401	5085.000	409.355
402	5085.000	436.452
403	5085.000	450.000
404	5190.000	34.839
405	5190.000	68.963
406	5190.000	103.088
407	5190.000	137.212
408	5190.000	171.337
409	5190.000	205.461
410	5190.000	239.586
411	5190.000	273.710
412	5190.000	307.835
413	5190.000	341.959
414	5190.000	376.084
415	5190.000	401.361
416	5190.000	414.000
417	5295.000	26.129
418	5295.000	57.797
419	5295.000	89.466
420	5295.000	121.134
421	5295.000	152.803
422	5295.000	184.471
423	5295.000	216.139
424	5295.000	247.808
425	5295.000	279.476
426	5295.000	311.145
427	5295.000	342.813
428	5295.000	366.271
429	5295.000	378.000
430	5400.000	17.419
431	5400.000	46.632
432	5400.000	75.844
433	5400.000	105.056
434	5400.000	134.268
435	5400.000	163.481
436	5400.000	192.693
437	5400.000	221.905
438	5400.000	251.117
439	5400.000	280.330
440	5400.000	309.542
441	5400.000	331.181
442	5400.000	342.000
443	5505.000	8.710
444	5505.000	35.466
445	5505.000	62.222
446	5505.000	88.978
447	5505.000	115.734
448	5505.000	142.490
449	5505.000	169.246
450	5505.000	196.003
451	5505.000	222.759
452	5505.000	249.515
453	5505.000	276.271
454	5505.000	296.090
455	5505.000	306.000
456	5610.000	0.0
457	5610.000	24.300
458	5610.000	48.600
459	5610.000	72.900
460	5610.000	97.200
461	5610.000	121.500
462	5610.000	145.800
463	5610.000	170.100
464	5610.000	194.400
465	5610.000	218.700
466	5610.000	243.000
467	5610.000	261.000
468	5610.000	270.000
469	5715.000	0.0
470	5715.000	24.300
471	5715.000	48.600
472	5715.000	72.900
473	5715.000	97.200
474	5715.000	121.500
475	5715.000	145.800
476	5715.000	170.100
477	5715.000	194.400
478	5715.000	218.700
479	5715.000	243.000
480	5715.000	261.000

Table B.4. (continued)

```
   481   5715.000    270.000
   482   5880.000      0.0
   483   5880.000     24.300
   484   5880.000     48.600
   485   5880.000     72.900
   486   5880.000     97.200
   487   5880.000    121.500
   488   5880.000    145.800
   489   5880.000    170.100
   490   5880.000    194.400
   491   5880.000    218.700
   492   5880.000    243.000
   493   5880.000    261.000
   494   5880.000    270.000
   495   6130.000      0.0
   496   6130.000     24.300
   497   6130.000     48.600
   498   6130.000     72.900
   499   6130.000     97.200
   500   6130.000    121.500
   501   6130.000    145.800
   502   6130.000    170.100
   503   6130.000    194.400
   504   6130.000    218.700
   505   6130.000    243.000
   506   6130.000    261.000
   507   6130.0      270.000
   508   6480.000      0.0
   509   6480.000     24.300
   510   6480.000     48.600
   511   6480.000     72.900
   512   6480.000     97.200
   513   6480.000    121.500
   514   6480.000    145.800
   515   6480.000    170.100
   516   6480.000    194.400
   517   6480.000    218.700
   518   6480.000    243.000
   519   6480.000    261.000
   520   6480.000    270.000
   521   6830.000      0.0
   522   6830.000     24.300
   523   6830.000     48.600
   524   6830.000     72.900
   525   6830.000     97.200
   526   6830.000    121.500
   527   6830.000    145.800
   528   6830.000    170.100
   529   6830.000    194.400
   530   6830.000    218.700
   531   6830.000    243.000
   532   6830.000    261.000
   533   6830.000    270.000
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
    1     1   14    15     2     1   12    40
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1       0.
  533        0.0
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
   23     0     1     2    24    25     0
C
C ------- DATA SET 13:  RAINFALL PROFILES
 0.0          2678400.0
   2.46E-6    2.46E-6
C
C ------- DATA SET 14:  RAINFALL TYPE AND PONDING DEPTH
   91     1     0      0.
  403     1    13        0.0
C
C ------- DATA SET 15:  RAINFALL-SEEPAGE SURFACE ELEMENT SIDE
   84    91   104      0
  360   390   403      1
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
  403       0 0.0
  533      13 0.0
  521       0 270.0
  522       0 245.7
  523       0 221.4
  524       0 197.1
```

BEST DOCUMENT AVAILABLE

Table B.4. (continued)

```
   525     0 172.8
   526     0 148.5
   527     0 124.2
   528     0 99.9
   529     0 75.6
   530     0 51.3
   531     0 27.0
   532     0 9.0
C
C ------- DATA SET 17 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18 THROUGH DATA SET 23 ARE NOT NEEDED SINCE KSS=0 AND NTI=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
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APPENDIX C: LIST OF FORTRAN SOURCE PROGRAM

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```
C                                                                       MAIN 005
C       ****************************************************           MAIN 010
C       *                                                  *           MAIN 015
C       *                    FEMWATER                      *           MAIN 020
C       *                                                  *           MAIN 025
C       ****************************************************           MAIN 030
C                                                                       MAIN 035
C                                                                       MAIN 040
C  THIS COMPUTER CODE IS CONTAINED IN THE FOLLOWING REPORT:            MAIN 045
C  YEH, G. T. AND D. S. WARD, 1980.  "FEMWATER: A FINITE-ELEMENT MODEL  MAIN 050
C  OF WATER FLOW THROUGH SATURATED-UNSATURATED POROUS MEDIA", ORNL-5567,MAIN 055
C  OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN 37830                  MAIN 060
C                                                                         CDC
C  THIS VERSION OF THE FEMWATER CODE IS MODIFIED TO OPERATE ON CDC       CDC
C  EQUIPMENT. NEW OR CHANGED STATEMENTS FOR THIS PURPOSE ARE MARKED      CDC
C  BY CDC BEGINNING IN COLUMN 75.                                        CDC
C                                                                       MAIN 065
C  A SLIGHTLY UPDATED VERSION IS CONTAINED IN:                         MAIN 070
C  YEH, G. T. AND R. H. STRAND, 1981. "FECWATER: USER'S MANUAL OF A    MAIN 075
C  FINITE ELEMENT COMPUTER CODE FOR SIMULATING WATER FLOW THROUGH      MAIN 080
C  SATURATED-UNSATURATED POROUS MEDIA," ORNL/TM-7316, OAK RIDGE        MAIN 085
C  NATIONAL LABORATORY, OAK RIDGE, TN. 37830                           MAIN 090
C                                                                       MAIN 095
C  FOR ANY QUESTION, PLEASE CONTACT DR. G. T. YEH AT (615) 574-7285    MAIN 100
C                                                                       MAIN 105
C  ADDITIONAL REFERENCES IS:                                           MAIN 110
C  REEVES, M. AND J. DUGUID, 1975. " WATER MOVEMENT THROUGH SATURATED- MAIN 115
C  UNSATURATED POROUS MEDIA: A GALERKIN FINITE ELEMENT MODEL ",        MAIN 120
C  ORNL 4927, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE,                MAIN 125
C  TENNESSEE 37830                                                     MAIN 130
C                                                                       MAIN 135
C                                                                       MAIN 140
C ------- MAIN PROGRAM                                                  MAIN 145
C                                                                       MAIN 150
      PROGRAM FEMWAT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2)  CDC
C                                                                         CDC
      IMPLICIT REAL   (A-H,O-Z)                                          CDC
C                                                                       MAIN 165
      DIMENSION X(595),Z(595),IE(528,5)                                 MAIN 170
C                                                                       MAIN 175
      DIMENSION C(595,21),R(595),H(595),HP(595),HW(595),HT(595),        MAIN 180
     > TH(528,4),DTH(528,4),VX(595),VZ(595),                            MAIN 185
     > AKX(528,4),AKZ(528,4),NPCNV(595)                                 MAIN 190
C                                                                       MAIN 195
      DIMENSION DLB(199),DCOSXB(199),DCOSZB(199),BFLX(200),BFLXP(200),  MAIN 200
     > NBF(199),ISB(199,4),NPB(200)                                     MAIN 205
C                                                                       MAIN 210
      DIMENSION DL(99),DCOSX(99),DCOSZ(99),DCYFLX(100),FLX(100),        MAIN 215
     > RSFLX(100),HCON(100),NRSE(99),IS(99,4),NPRS(100),NPCON(100),     MAIN 220
     > NPFLX(100),IRFTYP(100)                                             CDC
C                                                                       MAIN 230
C                                                                       MAIN 235
      DIMENSION RP(30),NPST(30), BB(40),NN(40)                          MAIN 240
C                                                                       MAIN 245
      DIMENSION PROP(3,5),THPROP(3,52),AKPROP(3,52),HPROP(3,52),        MAIN 250
     > CAPROP(3,52)                                                     MAIN 255
C                                                                       MAIN 260
      DIMENSION KPR(500),KDSK(500)                                      MAIN 275
C                                                                       MAIN 280
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                             MAIN 295
      COMMON /CNTRL/ NTI,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP
      COMMON /TOTLNS/ TOLA,TOLB
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX,DELTO
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
      COMMON /MTL/ NMAT,NMPPM,NSPPM
      COMMON /OPT/ ILUMP,IMID
C
      DATA MAXEL,MAXNP,MAXHBP /528,595,21/
      DATA MAXBEL,MAXBNP /199,200/
      DATA MXRSEL,MXRSNP /99,100/
      DATA MXSTEL,MXSTNP,MAXBCN /29,30,40/
      DATA MAXMAT,MXSPPM,MXMPPM /3,52,5/
      DATA MAXNTI /500/
C
C ------- INITIATE ARRAYS FOR NODAL POINTS
C
      DO 100 NP=1,MAXNP
         X(NP)=0.0
         Z(NP)=0.0
         R(NP)=0.0
         H(NP)=0.0
         HP(NP)=0.0
         HW(NP)=0.0
         HT(NP)=0.0
         VX(NP)=0.0
         VZ(NP)=0.0
         DO 100 IB=1,MAXHBP
  100       C(NP,IB)=0.0
C
C
C ------- INITIATE ARRAYS FOR ELEMENTS
C
      DO 150 MP=1,MAXEL
         DO 120 IQ=1,5
  120       IE(MP,IQ)=0
C
         DO 140 IQ=1,4
            TH(MP,IQ)=0.0
  140       DTH(MP,IQ)=0.0
C
  150    CONTINUE
C
C
C
C ------- INITIATE ARRAYS FOR BOUNDARY ELEMENTS
C
      DO 200 MP=1,MAXBEL
         DLB(MP)=0.0
         DCOSXB(MP)=0.0
         DCOSZB(MP)=0.0
         NBE(MP)=0
         DO 200 IQ=1,4
            ISB(MP,IQ)=0
  200    CONTINUE
C
C
C ------- INITIATE ARRAYS FOR BOUNDARY NODAL POINTS
C
      DO 250 NP=1,MAXBNP
```

```
          BFLX(NP)=0.0                                                  MAIN 665
          BFLXP(NP)=0.0                                                 MAIN 670
  250     NPB(NP)=0                                                     MAIN 675
C                                                                       MAIN 680
      DO 300 MP=1,MXRSEL                                                MAIN 685
          DL(MP)=0.0                                                    MAIN 690
          DCOSX(MP)=0.0                                                 MAIN 695
          DCOSZ(MP)=0.0                                                 MAIN 700
          NRSE(MP)=0                                                    MAIN 705
          DO 300 IQ=1,4                                                 MAIN 710
             IS(MP,IQ)=0                                                MAIN 715
  300     CONTINUE                                                      MAIN 720
C                                                                       MAIN 725
C                                                                       MAIN 730
C ------- INITIATE ARRAYS FOR RAINFALL-SEEPAGE BOUNDARY NODAL POINTS    MAIN 735
C                                                                       MAIN 740
      DO 350 NP=1,MXRSNP                                                MAIN 745
          DCYFLX(NP)=0.0                                                MAIN 750
          FLX(NP)=0.0                                                   MAIN 755
          RSFLX(NP)=0.0                                                 MAIN 760
          HCON(NP)=0.0                                                  MAIN 765
          NPRS(NP)=0                                                    MAIN 770
          NPCON(NP)=0                                                   MAIN 775
          NPFLX(NP)=0                                                   MAIN 780
  350     IRFTYP(NP)=0                                                  MAIN 785
C                                                                       MAIN 790
C                                                                       MAIN 840
C ------- INITIATE ARRAYS FOR SURFACE  TERM POINT FLUX                  MAIN 845
C                                                                       MAIN 850
      DO 500 NP=1,MXSTNP                                                MAIN 855
          NPST(NP)=0                                                    MAIN 860
  500     RP(NP)=0.0                                                    MAIN 865
C                                                                       MAIN 870
C                                                                       MAIN 875
C ------- INITIATE ARRAYS FOR DIRICHLENT BOUNDARY CONDITIONS            MAIN 880
C                                                                       MAIN 885
      DO 510 NP=1,MAXBCN                                                MAIN 890
          HB(NP)=0.0                                                    MAIN 895
  510     NN(NP)=0                                                      MAIN 900
C                                                                       MAIN 905
C                                                                       MAIN 910
C ------- INITIATE ARRAYS FOR MATERIAL PROPERTIES                       MAIN 915
C                                                                       MAIN 920
      DO 650 I=1,MAXMAT                                                 MAIN 925
          DO 610 J=1,MXMPPM                                             MAIN 930
  610         PROP(I,J)=0.0                                             MAIN 935
C                                                                       MAIN 940
          DO 630 J=1,MXSPPM                                             MAIN 945
              THPROP(I,J)=0.0                                           MAIN 950
              AKPROP(I,J)=0.0                                           MAIN 955
              HPROP(I,J)=0.0                                            MAIN 960
  630         CAPROP(I,J)=0.0                                           MAIN 965
C                                                                       MAIN 970
  650     CONTINUE                                                      MAIN 975
C                                                                       MAIN 980
C                                                                       MAIN1025
C ------- PASS THE PROGRAM TO GW2DXZ                                    MAIN1030
C                                                                       MAIN1035
      CALL GW2DXZ(X,Z,IE, C,R,H,HP,HW,HT,TH,DTH,VX,VZ,AKX,AKZ,NPCNV,    MAIN1040
     > DLB,DCOSXB,DCOSZB,BFLX,BFLXP,NBF,ISB,NPB,  DL,DCOSX,DCOSZ,       MAIN1045
     > DCYFLX,FLX,RSFLX,HCON,NRSF,IS,NPRS,NPCON,NPFLX,IRFTYP,                  CDC
     > RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP, KPR,KDSK,              CDC
     > MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,MXRSNP, MXSTEL,MXSTNP,        CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTT)                                          CDC
C                                                                           MAIN1080
      STOP                                                                  MAIN1085
      END                                                                   MAIN1090
      SUBROUTINE GW2DXZ(X,Z,IE, C,R,H,HP,HW,HT,TH,DTH,VX,VZ,AKX,AKZ,        GW2D 005
     > NPCNV,   DLB,DCOSXB,DCOSZB,BFLX,BFLXP,NBE,TSB,NPB,   DL,DCOSX,      GW2D 010
     > DCOSZ,DCYFLX,FLX,RSFLX,HCON,NRSF,IS,NPRS,NPCON,NPFLX,IRFTYP,           CDC
     > RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP, KPR,KDSK,              CDC
     > MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,MXRSNP, MXSTEL,MXSTNP,        CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTT)                                          CDC
C                                                                           GW2D 045
      IMPLICIT REAL  (A-H,O-Z)                                                 CDC
      REAL   PMAT,THPAR,AKPAR,SUBHD                                            CDC
C                                                                           GW2D 060
      DIMENSION TITLE(9)                                                    GW2D 065
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                               GW2D 070
C                                                                           GW2D 075
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP),HP(MAXNP),HW(MAXNP),      GW2D 080
     > HT(MAXNP),TH(MAXEL,4),DTH(MAXEL,4),VX(MAXNP),VZ(MAXNP),             GW2D 085
     > AKX(MAXEL,4),AKZ(MAXEL,4),NPCNV(MAXNP)                              GW2D 090
C                                                                           GW2D 095
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),BFLX(MAXBNP),     GW2D 100
     > BFLXP(MAXBNP),NBE(MAXBEL),TSB(MAXBEL,4),NPB(MAXBNP)                 GW2D 105
C                                                                           GW2D 110
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),DCYFLX(MXRSNP),      GW2D 115
     > FLX(MXRSNP),RSFLX(MXRSNP),HCON(MXRSNP),NRSF(MXRSEL),IS(MXRSEL,4),GW2D 120
     > NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP),IRFTYP(MXRSNP)                 CDC
C                                                                           GW2D 135
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)               GW2D 140
C                                                                           GW2D 145
      DIMENSION PROP(MAXMAT,5),THPROP(MAXMAT,MXSPPM),                          CDC
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM)   GW2D 155
C                                                                           GW2D 160
      DIMENSION KPR(MAXNTT),KDSK(MAXNTT)                                    GW2D 180
C                                                                              CDC
      DIMENSION TRF(3,20),RF(3,20),RFALL(3)                                    CDC
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)                                   CDC
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8),SUBHD(8,3)                     CDC
C                                                                           GW2D 185
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                                 GW2D 190
      COMMON /CNTRL/ NTT,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP          GW2D 195
      COMMON /TOTLNS/ TOLA,TOLB                                             GW2D 200
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX,DELTO                            GW2D 205
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR                       GW2D 210
      COMMON /BCST/ NBC,NST,NSTN                                            GW2D 215
      COMMON /MTL/ NMAT,NMPPM,NSPPM                                         GW2D 220
      COMMON /OPT/ ILUMP,TMID                                               GW2D 225
C                                                                           GW2D 230
C                                                                              CDC
      DATA PMAT/4H    ,4H ALP,4H    ,4H   B,4HETAP,4H    ,                     CDC
     > 4H POR,4H    ,4H    ,4H KX ,4H    ,4H    ,4H KZ ,4H    /                CDC
      DATA THPAR/4H    ,4H TH1,4H    ,4H    ,4H TH2,4H    ,                    CDC
     > 4H  H0 ,4H    ,4H    ,4H  A1,4H    ,4H    ,4H  A2,4H    ,4H    ,         CDC
     > 4H  B1,4H    ,4H    ,4H  B2,4H    ,4H    ,4H   C,4H    /                CDC
C                                                                              CDC
      DATA AKPAR/4H    ,4H  B1,4H    ,4H    ,4H  B2,4H    ,18*4H    /          CDC
C                                                                              CDC
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      DATA SUBHD/4HINPU,4HT IN,4HITIA,4HL CO,4HNDIT,4HIONS,2*4H          CDC
     > 4HSTEA,4HDY-S,4HTATE,4H INI,4HTIAL,4H CON,4HDITI,4HONS , 8*       CDC
     > 4H                                                                CDC
C                                                                        CDC
C                                                                        CDC
C ------- INITIATE ARRAYS FOR RAINFALL INFORMATION                        CDC
C                                                                        CDC
      DO 5 I=1,5                                                         CDC
         RFALL(I)=0.0                                                    CDC
         DO 5 J=1,20                                                     CDC
            TRF(I,J)=0.0                                                 CDC
    5       RF(I,J)=0.0                                                  CDC
C                                                                        CDC
C                                                                        CDC
C ------- INITIATE ARRAYS FOR FLOW THROUGH VARIOUS TYPES OF BOUNDARIES    CDC
C                                                                        CDC
      DO 8 I=1,10                                                        CDC
         FRATE(I)=0.0                                                    CDC
         FLOW(I)=0.0                                                     CDC
    8    TFLOW(I)=0.0                                                    CDC
C                                                                        CDC
C                                                                       GW2D 235
C  PROBLEM  IDENTIFICATION  AND  DESCRIPTION                            GW2D 240
C                                                                       GW2D 245
   10 READ 10000,NPROB, (TITLE(I),I=1,9),IBUG,ICHNG                     GW2D 250
      IF (NPROB.LE.0) GO TO 270                                         GW2D 255
      PRINT 10100,NPROB,(TITLE(I),I=1,9)                                GW2D 260
C                                                                       GW2D 265
C  READ AND PRINT INPUT DATA                                            GW2D 270
C                                                                       GW2D 275
      KOUT=0                                                            GW2D 280
      KSS=1                                                             GW2D 285
C                                                                       GW2D 290
C                                                                       GW2D 295
      CALL DATAIN(X,Z,IE, H,HT,TH,VX,VZ,  DLB,DCOSXB,DCOSZB,NBE,        GW2D 300
     > ISB,NPB,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,   GW2D 305
     > TRF,RF, RP,NPST, BR,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,          CDC
     > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,                   CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,        CDC
     > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, 1)                              CDC
C                                                                       GW2D 340
      KDIG=NSTRT                                                        GW2D 345
      IF (ISTOP.GT.0) GO TO 270                                         GW2D 350
C                                                                       GW2D 355
C  COMPUTE BAND-WIDTH VARIABLES                                         GW2D 360
C                                                                       GW2D 365
      IHALFB=MAXDIF                                                     GW2D 370
      IBAND=2*IHALFB+1                                                  GW2D 375
      IHBP=IHALFB+1                                                     GW2D 380
      IF (IHBP.GT.MAXHBP) GO TO 260                                     GW2D 385
C                                                                       GW2D 390
C  PREPARE INITIAL VARIABLES                                            GW2D 395
C                                                                       GW2D 400
      CALL SPROP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,         GW2D 405
     >            CAPROP, MAXEL,MAXNP, MAXMAT,       MXSPPM, NEL,KSP)   GW2D 410
C                                                                       GW2D 415
      CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)       GW2D 420
C                                                                       GW2D 425
      KFLOW=-1                                                          GW2D 430
C                                                                       GW2D 435
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      CALL SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,ISB,
     > NBE,NPB, NPRS,      NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,
     > MAXBEL,MAXBNP, MXRSNP,        MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,
     > PROP,MAXMAT)
C
C
C   PRINT INITIAL VARIABLES
C
      KDIAG=0
C
      CALL PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
     > TIME,DELT,SUBHD(1,1),IBAND,KPRO,KOUT,KDIAG,-1)
C
      IF(KSTR.EQ.1 .AND. KSS.EQ.1 .AND. NSTRT.EQ.0 .AND. KDSKO.EQ.1)
     > CALL STORE(X,Z,IE, H,HT,TH,VX,VZ,DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,
     > TITLE,TIME,MAXNP,MAXEL,MAXBNP,MAXBEL,NPROB,NNP,NEL,NBN,NBEL,NTT,
     > NPCON,NPFLX,MXRSNP,NRSN, NSTRT)
C
      IF (KSS.NE.0) GO TO 130
C
C   PERFORM STEADY-STATE CALCULATION
C
      IF (NRSN.EQ.0) GO TO 30
C
      DO 20 NPP=1,NRSN
         NPCON(NPP)=NPRS(NPP)
   20    NPFLX(NPP)=0
C
      NCHG=-1
      CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,
     > BCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL,  MAXEL,MAXNP,
     > MXRSEL,MXRSNP,                   TIME,NCHG)
C
   30 DO 40 NP=1,NNP
   40    HP(NP)=H(NP)
C
      NIT=0
      KDIG=KDIG+1
      IF(IBUG.NE.0) PRINT 10400,KDIG,TIME,DELT
C
C
C   ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS BEGINS
C
      DO 100 ICY=1,MAXCY
C        DO 50 NP=1,NNP
C  50       H(NP)=HP(NP)
C
C   ITERATION LOOP ON THE NON-LINEAR EQUATION BEGINS
C
         IF(IBUG.NE.0) PRINT 10401
         DO 80 IT=1,MAXIT
            NIT=NIT+1
C
C   EVALUATE SOIL PROPERTIES FOR PREVIOUS ITERATE
C
            CALL SPROP(IE, H,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,HPROP,
     >             CAPROP, MAXEL,MAXNP, MAXMAT,        MXSPPM, NEL,KSP)
C
C   ASSEMBLE STEADY-STATE COEFFICIENT MATRICES A, B, AND C, AND CONSTRUCT
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C   LOAD VECTOR R                                                       GW2D 740
C                                                                       GW2D 745
          CALL ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,            GW2D 750
     >      MAXNP,MAXEL,MAXHBP, MAXMAT,         KSS,W,DELT)             GW2D 755
C                                                                       GW2D 760
C   APPLY STEADY-STATE BOUNDARY CONDITTIONS                             GW2D 765
C                                                                       GW2D 770
          CALL BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST,RH,NN,             GW2D 775
     >          MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXHCN, KSS)                GW2D 780
C                                                                       GW2D 785
C   TRIANGULARIZE STEADY-STATE C MATRIX                                 GW2D 790
C                                                                       GW2D 795
          CALL BANSOL(1,C,R,NNP,IHBP,MAXNP,MAXHBP)                      GW2D 800
C                                                                       GW2D 805
C   BACK-SUBSTITUTE FOR STEADY-STATE SOLUTION                           GW2D 810
C                                                                       GW2D 815
          CALL BANSOL(2,C,R,NNP,IHBP,MAXNP,MAXHBP)                      GW2D 820
C                                                                       GW2D 825
C   OBTAIN MAXIMUM RELATIVE DEVIATION FROM PREVIOUS ITERATE             GW2D 830
C                                                                       GW2D 835
          NPP=0                                                         GW2D 840
          RD=-1.                                                        GW2D 845
          RES=-1.                                                       GW2D 850
          DO 60 NP=1,NNP                                                GW2D 855
             RESNP= ABS(R(NP)-H(NP))                                      CDC
             RES=AMAX1(RES,RESNP)                                         CDC
             IF (H(NP).NE.0.D0) RD=AMAX1(RD, ABS(RESNP/H(NP)))            CDC
             IF (RESNP.LE.TOLA) GO TO 60                                GW2D 875
             NPP=NPP+1                                                  GW2D 880
             NPCNV(NPP)=NP                                              GW2D 885
   60        CONTINUE                                                   GW2D 890
C                                                                       GW2D 895
C   UPDATE PRESSURE WITH CURRENT ITERATE                                GW2D 900
C                                                                       GW2D 905
          NNCVN=NPP                                                     GW2D 910
          DO 70 NP=1,NNP                                                GW2D 915
   70        H(NP)=R(NP)                                                GW2D 920
C                                                                       GW2D 925
C   ESCAPE FROM ITERATION LOOP IF THE MAXIMUM RESIDUAL IS               GW2D 930
C   SUFFICIENTLY SMALL                                                  GW2D 935
C                                                                       GW2D 940
          IF(IBUG.NE.0) PRINT 10200,NIT,RES,RD,NNCVN                    GW2D 945
          IF (IT.EQ.1) GO TO 80                                         GW2D 950
          IF (RES.LT.TOLA) GO TO 90                                     GW2D 955
   80     CONTINUE                                                      GW2D 960
      PRINT 10210, ICY,TT,MAXIT                                         GW2D 965
C                                                                       GW2D 970
C   END OF ITERATION LOOP ON THE NONO-LINEAR EQUATION                   GW2D 975
C                                                                       GW2D 980
C                                                                       GW2D 985
C   PRINT NONCONVERGING NODES                                           GW2D 990
C                                                                       GW2D 995
        IF(IBUG.EQ.0) GO TO 90                                          GW2D1000
        PRINT 10500                                                     GW2D1005
        PRINT 10600,(NPCNV(NPP),NPP=1,NNCVN)                            GW2D1010
C                                                                       GW2D1015
C                                                                       GW2D1020
C   PRINT RAINFALL-SEEPAGE B. C. CHANGE INFORMATION                     GW2D1025
C                                                                       GW2D1030
   90   IF(ICHNG.EQ.0) GO TO 95                                         GW2D1035
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      IF(NRSN.EQ.0) GO TO 95                                            GW2D1040
      PRINT 10402                                                       GW2D1045
      DO 94 IRSN=1,NRSN                                                 GW2D1050
         NP=NPRS(IRSN)                                                  GW2D1055
         PRINT 10403,IRSN,NP,NPCON(IRSN),HCON(IRSN),NPFLX(IRSN),        GW2D1060
     >    FLX(IRSN),DCYFLX(IRSN)                                        GW2D1065
 94      CONTINUE                                                       GW2D1070
C                                                                       GW2D1075
C  CALCULATE FLOW RATES                                                 GW2D1080
C                                                                       GW2D1085
 95   CALL SPROP(IE, H,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,HPROP,        GW2D1090
     >     CAPROP, MAXEL,MAXNP, MAXMAT,        MXSPPM, NEL,KSP)         GW2D1095
C                                                                       GW2D1100
      CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)       GW2D1105
C                                                                       GW2D1110
      IF (NRSN.EQ.0) GO TO 110                                          GW2D1115
C                                                                       GW2D1120
      CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,         GW2D1125
     > HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,        GW2D1130
     > MAXNP, MXRSEL,MXRSNP,                   TIME,NCHG)               GW2D1135
      IF (NCHG.EQ.0) GO TO 110                                          GW2D1140
 100  CONTINUE                                                          GW2D1145
     PRINT 10610, ICY,IT,MAXCY,MAXIT                                    GW2D1150
C                                                                       GW2D1155
C  END OF ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS    GW2D1160
C                                                                       GW2D1165
C                                                                       GW2D1170
 110 KFLOW=-1                                                           GW2D1175
     CALL SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,ISB,     GW2D1180
    > NBE,NPB, NPRS,      NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,       GW2D1185
    > MAXBEL,MAXBNP, MXRSNP,        MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,  GW2D1190
    > PROP,MAXMAT)                                                        CDC
C                                                                       GW2D1200
     DO 120 I=1,6                                                       GW2D1205
        FLOW(I)=0.                                                      GW2D1210
 120    TFLOW(I)=0.                                                     GW2D1215
     FRATE(7)=0.                                                        GW2D1220
     FLOW(7)=0.                                                         GW2D1225
C                                                                       GW2D1230
C                                                                       GW2D1235
C  PRINT STEADY-STATE VARIABLES                                         GW2D1240
C                                                                       GW2D1245
     CALL PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,       GW2D1250
    > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,  GW2D1255
    > TIME,DELT,SURHD(1,2),IBAND,KPRO,KOUT,KDIAG,0)                     GW2D1260
C                                                                       GW2D1265
     IF(KSTR.EQ.1 .AND. KDSKO.EQ.1) CALL STORE(X,Z,IE,                  GW2D1270
    > H,HT,TH,VX,VZ,DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,TITLE,TIME,MAXNP,     GW2D1275
    > MAXEL,MAXBNP,MAXBEL,NPROB,NNP,NEL,NBN,NBEL,NTI, NPCON,NPFLX,      GW2D1280
    > MXRSNP,NRSN, NSTRT)                                               GW2D1285
     IF (NTI.EQ.0) GO TO 10                                             GW2D1290
C                                                                       GW2D1295
C  READ TRANSIENT BOUNDARY CONDITIONS                                   GW2D1300
C                                                                       GW2D1305
     CALL DATAIN(X,Z,IE, H,HT,TH,VX,VZ,  DLB,DCOSXB,DCOSZB,NBE,         GW2D1310
    > ISB,NPB,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,    GW2D1315
    > TRF,RF, HP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,            CDC
    > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,                     CDC
    > MAXBCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,          CDC
    > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, 2)                                CDC
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C                                                                       GW2D1350
      KSS=1                                                             GW2D1355
C                                                                       GW2D1360
C  PERFORM TRANSIENT-STATE CALCULATION                                  GW2D1365
C                                                                       GW2D1370
  130 IF (NRSN.EQ.0) GO TO 160                                          GW2D1375
      IF (NSTRT.GT.0) GO TO 150                                         GW2D1380
C                                                                       GW2D1385
      DO 140 NPP=1,NRSN                                                 GW2D1390
         NPCON(NPP)=NPRS(NPP)                                           GW2D1395
  140    NPFLX(NPP)=0                                                   GW2D1400
C                                                                       GW2D1405
  150 NCHG=-1                                                           GW2D1410
C                                                                       GW2D1415
      CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,         GW2D1420
     > HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,MAXNP,  GW2D1425
     > MXRSEL,MXRSNP,                    TIME,NCHG)                       CDC
C                                                                       GW2D1435
  160 TIME=TIME+DELT                                                    GW2D1440
      W1=W                                                              GW2D1445
      W2=1.-W                                                           GW2D1450
      KFLOW=1                                                           GW2D1455
C                                                                       GW2D1460
C                                                                       GW2D1465
C  BEGIN THE TIME-MARCHING LOOP                                         GW2D1470
C                                                                       GW2D1475
      DO 250 ITM=1,NTT                                                  GW2D1480
C                                                                       GW2D1485
         DO 170 NP=1,NNP                                                GW2D1490
  170       HP(NP)=H(NP)                                                GW2D1495
C                                                                       GW2D1500
         NIT=0                                                          GW2D1505
         KDIG=KDIG+1                                                    GW2D1510
         IF(IBUG.NE.0) PRINT 10400,KDIG,TIME,DELT                       GW2D1515
C                                                                       GW2D1520
C  BEGIN THE ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS GW2D1525
C                                                                       GW2D1530
         DO 230 ICY=1,MAXCY                                             GW2D1535
            IF(IBUG.NE.0) PRINT 10401                                   GW2D1540
C                                                                       GW2D1545
            DO 180 NP=1,NNP                                             GW2D1550
  180          HW(NP)=HP(NP)                                            GW2D1555
C                                                                       GW2D1560
C  BEGIN THE ITERATION LOOP ON THE NON-LINEAR EQUATION                  GW2D1565
C                                                                       GW2D1570
            DO 210 IT=1,MAXIT                                           GW2D1575
               NIT=NIT+1                                                GW2D1580
C                                                                       GW2D1585
C  EVALUATE SOIL PROPERTIES FOR PREVIOUS ITERATE                        GW2D1590
C                                                                       GW2D1595
C              CALL SPROP(IE,HW,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,     GW2D1600
               CALL SPROP(IE,H, TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,     GW2D1605
     >          HPROP,CAPROP,MAXEL,MAXNP,MAXMAT,       MXSPPM,NEL,KSP)  GW2D1610
C                                                                       GW2D1615
C  ASSEMBLE COEFFICIENT MATRICES A, B, AND C, AND CONSTRUCT LOAD        GW2D1620
C  VECTOR R                                                             GW2D1625
C                                                                       GW2D1630
               CALL ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,       GW2D1635
     >          MAXNP,MAXEL,MAXBBP, MAXMAT,         KSS,W,DELT)         GW2D1640
C                                                                       GW2D1645
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C  APPLY BOUNDARY CONDITIONS                                            GW2D1650
C                                                                       GW2D1655
            CALL BC(C,R, FLX,BCON,NPCON,NPFLX, RP,NPST, BB,NN,          GW2D1660
  >              MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXBCN, KSS)               GW2D1665
C                                                                       GW2D1670
C  TRIANGULARIZE C MATRIX                                               GW2D1675
C                                                                       GW2D1680
            CALL BANSOL(1,C,R,NNP,IHBP,MAXNP,MAXHBP)                    GW2D1685
C                                                                       GW2D1690
C  BACK-SUBSTITUTE                                                      GW2D1695
C                                                                       GW2D1700
            CALL BANSOL(2,C,R,NNP,IHBP,MAXNP,MAXHBP)                    GW2D1705
C                                                                       GW2D1710
C  OBTAIN MAXIMUM RELATIVE DEVIATION FROM PREVIOUS ITERATE              GW2D1715
C                                                                       GW2D1720
            NPP=0                                                       GW2D1725
            RD=-1.                                                      GW2D1730
            RES=-1.                                                     GW2D1735
            DO 190 NP=1,NNP                                             GW2D1740
               RESNP= ABS(R(NP)-H(NP))                                    CDC
               RES=AMAX1(RES,RESNP)                                       CDC
               IF (H(NP).NE.0.D0) RD=AMAX1(RD, ABS(RESNP/H(NP)))          CDC
               IF (RESNP.LE.TOLB) GO TO 190                             GW2D1760
               NPP=NPP+1                                                GW2D1765
               NPCNV(NPP)=NP                                            GW2D1770
 190           CONTINUE                                                 GW2D1775
C                                                                       GW2D1780
            NNCVN=NPP                                                   GW2D1785
C                                                                       GW2D1790
C  UPDATE PRESSURE WITH CURRENT ITERATE                                 GW2D1795
C                                                                       GW2D1800
            DO 200 NP=1,NNP                                             GW2D1805
               H(NP)=R(NP)                                              GW2D1810
 200           HW(NP)=W1*H(NP)+W2*HP(NP)                                GW2D1815
C                                                                       GW2D1820
C  ESCAPE FROM ITERATION LOOP IF THE MAXIMUM RESIDUAL IS                GW2D1825
C  SUFFICIENTLY SMALL                                                   GW2D1830
C                                                                       GW2D1835
            IF(IBUG.NE.0) PRINT 10200,NIT,RES,RD,NNCVN                  GW2D1840
            IF (IT.EQ.1.AND.ITM.EQ.1) GO TO 210                         GW2D1845
            IF (RES.LT.TOLB) GO TO 220                                  GW2D1850
 210        CONTINUE                                                    GW2D1855
     PRINT 10710, ITM,TCY,IT,MAXIT                                      GW2D1860
C                                                                       GW2D1865
C  END THE ITERATION LOOP ON THE NON-LINEAR EQUATION                     GW2D1870
C                                                                       GW2D1875
          IF(IBUG.EQ.0) GO TO 220                                       GW2D1880
C                                                                       GW2D1885
C  PRINT NONCONVERGING NODES                                            GW2D1890
C                                                                       GW2D1895
          PRINT 10500                                                   GW2D1900
          PRINT 10600,(NPCNV(NPP),NPP=1,NNCVN)                          GW2D1905
C                                                                       GW2D1910
C  PRINT RAINFALL-SEEPAGE BOUNDARY CONDITION CHANGE INFORMATION         GW2D1915
C                                                                       GW2D1920
 220      IF(ICHNG.EQ.0) GO TO 225                                      GW2D1925
          IF(NRSN.EQ.0) GO TO 225                                       GW2D1930
          PRINT 10402                                                   GW2D1935
          DO 224 IRSN=1,NRSN                                            GW2D1940
             NP=NPRS(IRSN)                                              GW2D1945
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               PRINT 10403,IRSN,NP,NPCON(IRSN),HCON(IRSN),NPFLX(IRSN),   GW2D1950
    >           FLX(IRSN),DCYFLX(IRSN)                                   GW2D1955
  224          CONTINUE                                                  GW2D1960
C                                                                        GW2D1965
C  CALCULATE FLOW RATES                                                  GW2D1970
C                                                                        GW2D1975
  225        CALL SPROP(TE, H,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,HPROP,  GW2D1980
    >            CAPROP,MAXEL,MAXNP,MAXMAT,         MXSPPM,NEL,KSP)      GW2D1985
C                                                                        GW2D1990
             CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP) GW2D1995
C                                                                        GW2D2000
             IF (NRSN.EQ.0) GO TO 240                                    GW2D2005
C                                                                        GW2D2010
             CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,   GW2D2015
    >         HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,  GW2D2020
    >         MAXNP, MXRSEL,MXRSNP,                     TIME,NCHG)       GW2D2025
             IF (NCHG.EQ.0) GO TO 240                                    GW2D2030
  230        CONTINUE                                                    GW2D2035
      PRINT 10810, ITM,ICY,IT,MAXCY,MAXIT                                GW2D2040
C                                                                        GW2D2045
C  END THE ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS    GW2D2050
C                                                                        GW2D2055
C                                                                        GW2D2060
  240     IF(IMID.EQ.0) GO TO 245                                        GW2D2065
          DO 243 I=1,NNP                                                 GW2D2070
  243     H(I)=2.0D0*H(I) - HP(I)                                        GW2D2075
C                                                                        GW2D2080
          DO 244 I=1,NPC                                                 GW2D2085
          NI=NN(I)                                                       GW2D2090
  244     H(NI)=HH(I)                                                    GW2D2095
C                                                                        GW2D2100
  245     CALL SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,ISB, GW2D2105
     > NBE,NPB, NPRS,      NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,       GW2D2110
     > MAXBEL,MAXBNP, MXRSNP,       MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,   GW2D2115
     > PROP,MAXMAT)                                                        CDC
C                                                                        GW2D2125
C  PRINT VARIABLES AT EACH TIME STEP                                     GW2D2130
C                                                                        GW2D2135
      CALL PRINIT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,       GW2D2140
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,  GW2D2145
     > TIME,DELT,SURHD(1,3),IBAND,KPR(ITM),KOUT,KDIAG,ITM)               GW2D2150
C                                                                        GW2D2155
      IF(KSTR.EQ.1 .AND.KDSK(ITM).EQ.1) CALL STORE(X,Z,TE,H,HT,TH,VX,VZ,GW2D2160
     >     DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,TITLE,TIME,MAXNP,MAXEL,MAXBNP,  GW2D2165
     >     MAXBEL,NPROB,NNP,NEL,NBN,NBEL,NTI, NPCON,NPFLX,MXRSNP,NRSN,   GW2D2170
     >     NSTRT)                                                        GW2D2175
C                                                                        GW2D2180
C  PREPARE FOR NEXT TIME STEP                                            GW2D2185
C                                                                        GW2D2190
          IF (TIME.GT.TMAX) GO TO 10                                     GW2D2195
          DELT=DELT*(1.+CHNG)                                            GW2D2200
          DELT=AMIN1(DELT,DELMAX)                                          CDC
          TIME=TIME+DELT                                                 GW2D2210
  250     CONTINUE                                                       GW2D2215
C                                                                        GW2D2220
C  END OF TIME-MARCHING LOOP                                             GW2D2225
C                                                                        GW2D2230
C                                                                        GW2D2235
      GO TO 10                                                           GW2D2240
  260 PRINT 10500,IHBP,MAXHBP                                            GW2D2245
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C                                                                        GW2D2250
  270 RETURN                                                             GW2D2255
C                                                                        GW2D2260
10000 FORMAT(I5,9A8,1X,2I1)                                              GW2D2265
10100 FORMAT(/8H1PROBLEM,I5,3H.. ,9A8/)                                  GW2D2270
10200 FORMAT(5X,I10,3X,F12.4,3X,E12.4,15X,I10)                           GW2D2275
10300 FORMAT(///26H HALF-BANDWIDTH-PLUS-ONE =,I4,                        GW2D2280
     > 25H EXCEEDS MAX. ALLOWABLE =,I4)                                  GW2D2285
10400 FORMAT(1H1,52H****************************************************GW2D2290
     > 62H**************************************************************GW2D2295
     > 5H*****///17H DIAGNOSTIC TABLE,I4,12H.. AT TIME =,1PE12.4,        GW2D2300
     > 9H ,(DELT = 1PE12.4,1H))                                          GW2D2305
10401 FORMAT(///30H TABLE OF ITERATIVE PARAMETERS// 6X,                  GW2D2310
     > 9HITERATION,7X,8HRESIDUAL,6X,9HDEVIATION,6X,                      GW2D2315
     > 19HNO. NON-CONV. NODES)                                           GW2D2320
10402 FORMAT(//44H TABLE OF RAINFALL-SEEPAGE B. C. INFORMATION,/ 6X,     GW2D2325
     > 87HIRSN   NPRS(IRSN)   NPCON(IRSN)   HCON(NPRS)   NPFLX(IRSN)     GW2D2330
     > FLX(NPRS)   DCYFLX(NPRS))                                         GW2D2335
10403 FORMAT(1H ,I10,I13,I15,E13.4,I15,E13.3,E15.3)                      GW2D2340
10500 FORMAT(//30H TABLE OF NON-CONVERGING NODES)                        GW2D2345
10600 FORMAT(/(5X,20I5))                                                 GW2D2350
10210 FORMAT(1H0,'WARNING: NON-CONVERGENCE OCCUR DURING STEADY STATE SOLGW2D2355
     1UTION AT',I3,' -TH CYCLE'/1H ,'IT = ',I3,'  .GT.  MAXIT = ',I3)    GW2D2360
10610 FORMAT(1H0,'ABSOLUTELY WARNING: STEADY STATE SOLUTION IS NG'/1H ,  GW2D2365
     > 'ICY = ',I3,'  IT = ',I3,'  MAXCY = ',I3,'  MAXIT = ',I3)         GW2D2370
10710 FORMAT(1H0,'WARNING: NON-CONVERGENCE OCCUR AT',I5,' -TH TIME STEP'GW2D2375
     >,I3,' -TH CYCLE'/1H ,'IT = ',I3,'  .GT.  MAXIT = ',I3)             GW2D2380
10810 FORMAT(1H0,'ABSOLUTELY WARNING: TRANSIENT SOLUTION IS NG AT ',I5,  GW2D2385
     > ' -TH TIME STEP'/1H ,'ICY = ',I3,'  IT = ',I3,'  MAXCY = ',I3,    GW2D2390
     > '  MAXIT = ',I3)                                                  GW2D2395
      END                                                                GW2D2400
      SUBROUTINE DATAIN(X,Z,IE, H,HT,TH,VX,VZ, DLB,DCOSXB,DCOSZB,NBE,    DATA 005
     > ISB,NPB,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,    DATA 010
     > IRF,RF, RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,             CDC
     > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,                      CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,           CDC
     > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, IPASS)                             CDC
C                                                                        DATA 045
C                                                                        DATA 050
C  FUNCTION OF SUBROUTINE--TO READ, PRINT, AND CHECK VARIABLES           DATA 055
C  PERTAINING TO SIMULATION TIME, GEOMETRY OF THE SYSTEM, ITS SOIL       DATA 060
C  PROPERTIES, BOUNDARY-INITIAL CONDITIONS FOR BOTH STEADY-STATE AND     DATA 065
C  TRANSIENT CASES, AND NUMERICAL CONVERGENCE CRITERIA.                  DATA 070
C                                                                        DATA 075
C                                                                        DATA 080
C                                                                        DATA 085
      IMPLICIT REAL  (A-H,O-Z)                                              CDC
      REAL   PMAT,THPAR,AKPAR                                               CDC
C                                                                        DATA 100
      DIMENSION TITLE(9)                                                 DATA 105
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                            DATA 110
C                                                                        DATA 115
      DIMENSION H(MAXNP),HT(MAXNP),TH(MAXEL,4),VX(MAXNP),VZ(MAXNP)       DATA 120
C                                                                        DATA 125
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),   DATA 130
     > ISB(MAXBEL,4),NPB(MAXBNP)                                         DATA 135
C                                                                        DATA 140
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),HCON(MXRSNP),     DATA 145
     > NRSE(MXRSEL),IS(MXRSEL,4),NPRS(MXRSNP),NPCON(MXRSNP),             DATA 150
     > NPFLX(MXRSNP),IRFTYP(MXRSNP)                                         CDC
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C                                                                       DATA 165
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)           DATA 170
      DIMENSION PROP(MAXMAT,3),THPROP(MAXMAT,MXSPPM),                     CDC
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM) DATA 180
C                                                                       DATA 185
      DIMENSION KPR(MAXNTT),KDSK(MAXNTT)                                DATA 195
C                                                                         CDC
      DIMENSION TRF(3,20),RF(3,20)                                        CDC
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8)                           CDC
C                                                                       DATA 200
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                             DATA 205
      COMMON /CNTRL/ NTT,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP      DATA 210
      COMMON /TOTLNS/ TOLA,TOLB                                         DATA 215
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX,DELTO                        DATA 220
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR                   DATA 225
      COMMON /BCST/ NBC,NST,NSTN                                        DATA 230
      COMMON /MTL/ NMAT,NMPPM,NSPPM                                     DATA 235
      COMMON /OPT/ ILUMP,TMID                                           DATA 240
C                                                                       DATA 245
      IF (KSS.EQ.0) GO TO 505                                           DATA 250
      ISTOP=0                                                           DATA 255
C                                                                       DATA 260
      READ 12000,NNP,NEL,NMAT,NCM,NTT,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,     DATA 265
     >            NSTRT,MAXIT,MAXCY,NMPPM                               DATA 270
      READ 12000, ILUMP,TMID                                            DATA 275
      READ 12300, DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W    DATA 280
      DELTO=DELT                                                        DATA 285
      READ 12100,KPRO,(KPR(ITM),ITM=1,NTT)                              DATA 290
      READ 12100, KDSKO,(KDSK(ITM),ITM=1,NTT)                           DATA 295
C                                                                       DATA 300
      IF(TMAX.LE.0.0) TMAX=1.0E50                                       DATA 305
C                                                                       DATA 310
      PRINT 10000,NNP,NEL,NMAT,NCM,NTT,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,    DATA 315
     > NSTRT,MAXIT,MAXCY                                                DATA 320
      PRINT 10001, ILUMP,TMID                                           DATA 325
      PRINT 10100,DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W    DATA 330
      PRINT 10200                                                       DATA 335
      PRINT 12200,KPRO,(KPR(ITM),ITM=1,NTT)                             DATA 340
      PRINT 10201                                                       DATA 345
      PRINT 12200, KDSKO,(KDSK(ITM),ITM=1,NTT)                          DATA 350
C                                                                       DATA 355
      PI=3.14159265                                                     DATA 360
      FE=FE*PI/180.                                                     DATA 365
      SNFE= SIN(FE)                                                       CDC
      CSFE= COS(FE)                                                       CDC
      IF (KGRAV.EQ.0) SNFE=0.                                           DATA 380
      IF (KGRAV.EQ.0) CSFE=0.                                           DATA 385
C                                                                       DATA 390
C                                                                       DATA 395
C   READ AND PRINT MATERIAL PROPERTIES                                  DATA 400
C                                                                       DATA 405
   70 IF (NMPPM.LE.0) GO TO 90                                          DATA 410
      IF (NMAT.LE.0) GO TO 90                                           DATA 415
      PRINT 10300,((PMAT(I,J),I=1,3),J=1,NMPPM)                         DATA 420
      DO 80 I=1,NMAT                                                    DATA 425
         READ 12300,(PROP(I,J),J=1,NMPPM)                               DATA 430
   80    PRINT 12500,I,(PROP(I,J),J=1,NMPPM)                            DATA 435
   90 IF (KSP.EQ.1) GO TO 120                                           DATA 440
C                                                                       DATA 445
C                                                                       DATA 450
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C  SOIL PROPERTIES ARE TO BE REPRESENTED BY ANALYTIC FUNCTIONS
C
C
C  READ AND PRINT MOISTURE-CONTENT PARAMETERS
C
      IF (NSPPM.EQ.0) GO TO 200
      PRINT 10500,((THPAR(I,J),I=1,3),J=1,NSPPM)
      DO 100 I=1,NMAT
         READ 12300, (THPROP(I,J),J=1,NSPPM)
         PRINT 12700, I,(THPROP(I,J),J=1,NSPPM)
 100     CONTINUE
C
C  READ AND PRINT CONDUCTIVITY PARAMETERS
C
      PRINT 10600,((AKPAR(I,J),I=1,3),J=1,NSPPM)
      DO 110 I=1,NMAT
         READ 12300, (AKPROP(I,J),J=1,NSPPM)
         PRINT 12700, I,(AKPROP(I,J),J=1,NSPPM)
 110     CONTINUE
      GO TO 200
 120  IF (NSPPM.EQ.0) GO TO 200
C
C  SOIL PROPERTIES ARE TO BE GIVEN IN TABULAR FORM
C
C
C  READ PRESSURES
C
      DO 130 I=1,NMAT
         READ 12300, (HPROP(I,J),J=1,NSPPM)
 130     CONTINUE
C
C  READ WATER CONTENTS
C
      DO 140 I=1,NMAT
         READ 12300, (THPROP(I,J),J=1,NSPPM)
 140     CONTINUE
C
C  READ CONDUCTIVITIES OR PERMEABILITIES
C
      DO 150 I=1,NMAT
         READ 12300, (AKPROP(I,J),J=1,NSPPM)
 150     CONTINUE
C
C  READ WATER CAPACITIES
C
      DO 160 I=1,NMAT
         READ 12300, (CAPROP(I,J),J=1,NSPPM)
 160     CONTINUE
      PRINT 10400
      DO 170 I=1,NMAT
         PRINT 12600,I,(HPROP(I,J),THPROP(I,J),AKPROP(I,J),CAPROP(I,J),
     >     J=1,NSPPM)
 170     CONTINUE
      IF (KCP.EQ.0) GO TO 200
C
C  CONVERT FROM PERMEABILITY TO CONDUCTIVITY IF NECESSARY
C
      DO 190 I=1,NMAT
         PKCF=RHO*GRAV/VISC
         PROP(I,4)=PROP(I,4)*PKCF
      PROP(I,5)=PROP(I,5)*PKCF
      DO 180 J=1,NSPPM
 180     AKPROP(I,J)=AKPROP(I,J)*PKCF
 190  CONTINUE
C
C  READ AND PRINT NODAL-POINT DATA
C
 200 NI=1
 210 READ 12800, NJ,X(NJ),Z(NJ)
     IF (NJ-NI) 220,250,230
 220 PRINT 15100, NJ
     PRINT 12900, NJ,X(NJ),Z(NJ)
     ISTOP=ISTOP+1
     GO TO 210
 230 DF=NJ+1-NI
     DX=(X(NJ)-X(NI-1))/DF
     DZ=(Z(NJ)-Z(NI-1))/DF
 240 CONTINUE
     X(NI)=X(NI-1)+DX
     Z(NI)=Z(NI-1)+DZ
 250 NI=NI+1
     IF (NJ-NI) 260,250,240
 260 IF (NI.LE.NNP) GO TO 210
     PRINT 10700
     KLINE=0
C
     DO 265 NI=1,NNP,4
        NJMN=NI
        NJMX=MIN0(NI+3,NNP)
        PRINT 12900,(NJ,X(NJ),Z(NJ),NJ=NJMN,NJMX)
        KLINE=KLINE+1
 265 IF(MOD(KLINE,50).EQ.0) PRINT 10700
     INPTAB=6
C
C
C  READ AND PRINT ELEMENT DATA
C
C  ALSO COMPUTE MAXIMUM NODAL DIFFERENCE FOR EACH ELEMENT
C
     PRINT 10800
     KLINE=0
     MAXDIF = 0
     MJ = 0
 270 READ 12000, MI,(IE(MI,I),I=1,5),MODL,NLAY
     MTYP=IE(MI,5)
     MND = 0
     DO 280 IQ=1,3
        IQ1 = IQ + 1
        DO 280 JQ=IQ1,4
           ND = IABS(IE(MI,IQ)-IE(MI,JQ))
           MND = MAX0(ND,MND)
 280       MAXDIF = MAX0(ND,MAXDIF)
 290 MJ = MJ + 1
     IF (MI-MJ) 300,330,310
 300 PRINT 15200, MI
     PRINT 13000, MI,(IE(MI,I),I=1,5),MND
     ISTOP = ISTOP + 1
 310 DO 320 IQ=1,4
 320    IE(MJ,IQ) = IE(MJ-1,IQ) + 1
     IE(MJ,5) = IE(MJ-1,5)
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  330 PRINT 13000, MJ,(IE(MJ,I),I=1,5),MND                              DATA1055
      IF (MJ.LT.MI) GO TO 290                                           DATA1060
      IF (MJ.EQ.NEL) GO TO 370                                          DATA1065
      IF (MODL.LE.0) GO TO 270                                          DATA1070
      DO 360 I=1,NLAY                                                   DATA1075
         LL=2                                                           DATA1080
         DO 360 J=1,MODL                                                DATA1085
            IF (MJ.EQ.MI) GO TO 350                                     DATA1090
            DO 340 KQ=1,4                                               DATA1095
  340          IE(MJ,KQ) = IE(MJ-1,KQ) + LL                             DATA1100
            IE(MJ,5)=IE(MJ-1,5)                                         DATA1105
            PRINT 13000, MJ,(IE(MJ,K),K=1,5),MND                        DATA1110
            KLINE=KLINE+1                                               DATA1115
            IF(MOD(KLINE,50).EQ.0) PRINT 10800                          DATA1120
  350       LL = 1                                                      DATA1125
  360       MJ = MJ + 1                                                 DATA1130
      MJ = MJ - 1                                                       DATA1135
      IF (MJ.LT.NEL) GO TO 270                                          DATA1140
  370 CONTINUE                                                          DATA1145
C                                                                       DATA1150
C  MODIFY MATERIAL TYPES FOR SELECTED ELEMENTS IF NECESSARY             DATA1155
C                                                                       DATA1160
      IF (NCM.LE.0) GO TO 410                                           DATA1165
      PRINT 10900                                                       DATA1170
      L=0                                                               DATA1175
  380 READ 12000, MI,MTYP,MK,MINC                                       DATA1180
      IE(MI,5) = MTYP                                                   DATA1185
      PRINT 13100, MI,IE(MI,5)                                          DATA1190
      L = L + 1                                                         DATA1195
      IF (MK.LE.MI) GO TO 400                                           DATA1200
      IF (MINC.LE.0) MINC = 1                                           DATA1205
      MI = MI + MINC                                                    DATA1210
      DO 390 MJ=MI,MK,MINC                                              DATA1215
         IE(MJ,5) = MTYP                                                DATA1220
         PRINT 13100, MJ,IE(MJ,5)                                       DATA1225
  390    L = L + 1                                                      DATA1230
  400 IF (L.LT.NCM) GO TO 380                                           DATA1235
  410 CONTINUE                                                          DATA1240
      DO 420 M=1,NEL                                                    DATA1245
         MTYP=IE(M,5)                                                   DATA1250
         IF (MTYP.GT.0.AND.MTYP.LE.NMAT) GO TO 420                      DATA1255
         PRINT 15900,M                                                  DATA1260
         ISTOP=ISTOP+1                                                  DATA1265
  420    CONTINUE                                                       DATA1270
      IF(ISTOP.EQ.0) GO TO 430                                          DATA1275
      PRINT 15000, ISTOP                                                DATA1280
      STOP                                                              DATA1285
C                                                                       DATA1290
C  READ INITIAL CONDITIONS                                              DATA1295
C                                                                       DATA1300
  430 TIME=0.0D0                                                        DATA1305
      IF (NSTRT.EQ.0) GO TO 450                                         DATA1310
      REWIND 1                                                          DATA1315
      REWIND 2                                                          DATA1320
      READ(2) (DUM,I=1,9),IDUM,NPT,NET,NBN,NBEL,IDUM,NRBN               DATA1325
      IF (KSTR.EQ.1) WRITE(1) (TITLE(I),I=1,9),NPROB,NNP,NEL,NBN,NBEL,  DATA1330
     > NTI,NRBN                                                         DATA1335
      READ(2) (X(NP),NP=1,NPT),(Z(NP),NP=1,NPT),((IE(M,IQ),M=1,NET),IQ= DATA1340
     > 1,4),(DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),                     DATA1345
     > (DCOSZB(M),M=1,NBEL),(NBE(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ= DATA1350
     > 1,4),(NPB(NP),NP=1,NBN)
      IF (KSTR.EQ.1) WRITE(1) (X(NP),NP=1,NNP),(Z(NP),NP=1,NNP), ((IE(M,
     > IQ),M=1,NEL),IQ=1,4),(DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),
     > (DCOSZB(M),M=1,NBEL),(NBF(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ=
     > 1,4),(NPB(NP),NP=1,NBN)
      DO 440 ITM=1,NSTRT
         READ(2) TIME,(H(NP),NP=1,NPT),(HT(NP),NP=1,NPT),((TH(M,IQ),M=1,
     >     NEL),IQ=1,4),(VX(NP),NP=1,NPT),(VZ(NP),NP=1,NPT),
     >              (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)
         IF (KSTR.EQ.0) GO TO 440
         WRITE(1) TIME,(H(NP),NP=1,NNP),(HT(NP),NP=1,NNP),((TH(M,IQ),M=
     >     1,NEL),IQ=1,4),(VX(NP),NP=1,NNP),(VZ(NP),NP=1,NNP),
     >     (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)
  440    CONTINUE
      GO TO 500
  450 NI = 0
      NJ = 0
  460 IF (NJ.EQ.NNP) GO TO 500
      READ 13600,NJ,H(NJ)
  470 NI = NI + 1
      IF (NI.GT.1) GO TO 480
      IF (NJ.EQ.1) GO TO 480
      PRINT 15300,NJ
      ISTOP=ISTOP+1
      GO TO 500
  480 IF (NJ.EQ.NI) GO TO 460
      IF (NJ.GT.NI) GO TO 490
      PRINT 15300,NJ
      ISTOP=ISTOP+1
      GO TO 500
  490 H(NI)=H(NI-1)
      GO TO 470
C
C  IDENTIFY BOUNDARY ELEMENTS AND COMPUTE DIRECTION COSINES OF
C  BOUNDARY SIDES
C
  500 CALL SURF(X,Z,IE, DLB,DCOSXB,DCOSZB,NBF,ISB,NPB,
     > MAXNP,MAXEL, MAXBEL,MAXBNP)
      IF(KSS.EQ.1) GO TO 505
      NRSN=0
C
C  READ  STEADY STATE OR TRANSIENT PARAMETERS
C
  505 READ 12000,NBC,NST,NRFPR,NRFPAR,NRSEL,NRSN
C
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11000, INPTAB,NBC,NST,
     > NRFPR,NRFPAR,NRSEL,NRSN
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11300, INPTAB,NBC,NST,
     > NRFPR,NRFPAR,NRSEL,NRSN
      IF(KSS.EQ.1) PRINT 11300, INPTAB,NBC,NST,NRFPR,NRFPAR,NRSEL,NRSN
C
C
C  READ AND PRINT STEADY STATE OR TRANSIENT RAINFALL-SEEPAGE INFORMAT.
C
  570 IF (NRSN.EQ.0) GO TO 800
C
C  STEADY STATE OR TRANSIENT RAINFALL PROFILES
C
      IF (NRFPR.EQ.0) GO TO 590
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11400, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11410, INPTAB
      IF(KSS.EQ.1) PRINT 11410,INPTAB
      DO 580 I=1,NRFPR
         READ 12300,(TRF(I,J),J=1,NRFPAR)
         READ 12300,(RF(I,J),J=1,NRFPAR)
         PRINT 11500,I
         DO 580 J=1,NRFPAR
  580       PRINT 12400,(TRF(I,J),RF(I,J))
C
C  STEADY STATE OR TRANSIENT RAINFALL TYPES AND PONDING DEPTH
C
  590 CONTINUE
      NPP=0
  610 IF (NPP.EQ.NRSN) GO TO 670
      IF (NPP.LT.NRSN) GO TO 620
      PRINT 14800,NRSN
      ISTOP=ISTOP+1
      GO TO 670
  620 READ 13400,NI,ITYP,NPINC,HCONI
      IF (NPINC.GT.0) GO TO 640
  630 NPP=NPP+1
      NPRS(NPP)=NI
      IRFTYP(NPP)=ITYP
      HCON(NPP)=HCONI
      GO TO 610
  640 IF (NPP.GT.0) GO TO 650
      ISTOP=ISTOP+1
      PRINT 15500
  650 NJ=NPRS(NPP)
      JTYP=IRFTYP(NPP)
      HCONJ=HCON(NPP)
      NJ=NJ+NPINC
      NK=NI-1
      DO 660 NP=NJ,NK,NPINC
         NPP=NPP+1
         NPRS(NPP)=NP
         IRFTYP(NPP)=JTYP
  660    HCON(NPP)=HCONJ
      GO TO 630
  670 CONTINUE
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11600, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11610, INPTAB
      IF(KSS.EQ.1) PRINT 11610, INPTAB
      DO 680 NPP=1,NRSN
         NP=NPRS(NPP)
  680    PRINT 13500,NP,IRFTYP(NPP),HCON(NPP)
C
C  STEADY STATE OR TRANSIENT RAINFALL-SEEPAGE ELEMENT SURFACE INFORMAT.
C
      MPI=0
  690 IF (MPI.EQ.NRSEL) GO TO 740
      READ 12000,MI,IS1,IS2,KINC
      IF (KINC.GT.0) GO TO 710
  700 MPI=MPI+1
      NRSE(MPI)=MI
      IS(MPI,1)=IS1
      IS(MPI,2)=IS2
      GO TO 690
  710 IF (MPI.GT.0) GO TO 720
      ISTOP=ISTOP+1
      PRINT 15600
  720 NPINC=IS(MPI,2)-IS(MPI,1)
      MINC=IABS(NPINC)-1
      MINC=MAX0(MINC,1)
      MJ=NRSE(MPI)+MINC
      MK=MI-1
      DO 730 M=MJ,MK,MINC
         MPJ=MPI
         MPI=MPI+1
         NRSE(MPI)=M
         IS(MPI,1)=IS(MPJ,1)+NPINC
  730    IS(MPI,2)=IS(MPJ,2)+NPINC
      GO TO 700
  740 CONTINUE
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11700, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11710, INPTAB
      IF(KSS.EQ.1) PRINT 11710, INPTAB
      DO 750 MP=1,NRSEI
         M=NRSE(MP)
  750    PRINT 13000,M,IS(MP,1),IS(MP,2)
C
C  DETERMINE DIRECTION COSINES FOR STEADY STATE OR TRANSIENT
C  RAINFALL-SEEPAGE SURFACES
C
      DO 790 MPI=1,NRSEI
         MI=NRSE(MPI)
         DO 780 MPJ=1,NBEI
            MJ=NBE(MPJ)
            IF (MJ.NE.MI) GO TO 780
            IF (ISB(MPJ,1).EQ.IS(MPI,1).AND.ISB(MPJ,2).EQ.IS(MPI,2)) GO
    >        TO 760
            IF (ISB(MPJ,1).EQ.IS(MPI,2).AND.ISB(MPJ,2).EQ.IS(MPI,1)) GO
    >        TO 760
            GO TO 780
  760       DO 770 J=1,4
  770          IS(MPI,J)=ISB(MPJ,J)
            DL(MPI)=DLB(MPJ)
            DCOSX(MPI)=DCOSXB(MPJ)
            DCOSZ(MPI)=DCOSZB(MPJ)
            GO TO 790
  780       CONTINUE
         ISTOP=ISTOP+1
         PRINT 14900,MI
  790    CONTINUE
  800 DO 810 NP=1,MXSTNP
  810    RP(NP)=0.
      IF (NBC.EQ.0) GO TO 900
C
C  READ STEADY STATE OR TRANSIENT BOUNDARY CONDITIONS OF THE FORM H=HB
C
      NPP=0
  820 IF (NPP.EQ.NBC) GO TO 880
      IF (NPP.LT.NBC) GO TO 830
      PRINT 14300,NBC
      ISTOP=ISTOP+1
      GO TO 880
  830 READ 13300,NI,NPINC,BBI                                           DATA2255
      IF (NPINC.GT.0) GO TO 850                                         DATA2260
  840 NPP=NPP+1                                                         DATA2265
      NN(NPP)=NI                                                        DATA2270
      BB(NPP)=BBI                                                       DATA2275
      GO TO 820                                                         DATA2280
  850 IF (NPP.GT.0) GO TO 860                                           DATA2285
      ISTOP=ISTOP+1                                                     DATA2290
      PRINT 15400                                                       DATA2295
  860 NJ=NN(NPP)+NPINC                                                  DATA2300
      BBJ=BB(NPP)                                                       DATA2305
      NK=NI-1                                                           DATA2310
      DO 870 NP=NJ,NK,NPINC                                             DATA2315
         NPP=NPP+1                                                      DATA2320
         NN(NPP)=NP                                                     DATA2325
  870    BB(NPP)=BBJ                                                    DATA2330
      GO TO 840                                                         DATA2335
  880 CONTINUE                                                          DATA2340
      INPTAB=INPTAB+1                                                   DATA2345
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11100, INPTAB                 DATA2350
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11110, INPTAB                 DATA2355
      IF(KSS.EQ.1) PRINT 11110, INPTAB                                  DATA2360
      DO 890 NPP=1,NBC                                                  DATA2365
  890    PRINT 13200,NN(NPP),BB(NPP)                                    DATA2370
  900 IF (NST.LE.0) GO TO 1000                                          DATA2375
C                                                                       DATA2380
C  READ STEADY STATE OR TRANSIENT SURFACE-TERM POINT FLUXES             DATA2385
C                                                                       DATA2390
      NPP=0                                                             DATA2395
      MP=0                                                              DATA2400
      INPTAB=INPTAB+1                                                   DATA2405
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11200, INPTAB                 DATA2410
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11210, INPTAB                 DATA2415
      IF(KSS.EQ.1) PRINT 11210, INPTAB                                  DATA2420
  910 IF (MP.EQ.NST) GO TO 960                                          DATA2425
      READ 13400,NI,NJ,KINC,EI,EJ                                       DATA2430
      IF (KINC.GT.0) GO TO 930                                          DATA2435
  920 MP=MP+1                                                           DATA2440
      DX=X(NI)-X(NJ)                                                    DATA2445
      DZ=Z(NI)-Z(NJ)                                                    DATA2450
      EL= SQRT(DX*DX+DZ*DZ)                                               CDC
      PRINT 13500,NI,NJ,EI,EJ                                           DATA2460
      IF(MP.GT.1) GO TO 921                                             DATA2465
      NPP=NPP+1                                                         DATA2470
      NPST(NPP)=NI                                                      DATA2475
      NII=NPP                                                           DATA2480
      NPP=NPP+1                                                         DATA2485
      NPST(NPP)=NJ                                                      DATA2490
      NJJ=NPP                                                           DATA2495
      GO TO 928                                                         DATA2500
  921 DO 922 I=1,NPP                                                    DATA2505
         IJ=NPST(I)                                                     DATA2510
         IF(IJ.EQ.NI) GO TO 923                                         DATA2515
  922    CONTINUE                                                       DATA2520
      NPP=NPP+1                                                         DATA2525
      NPST(NPP)=NI                                                      DATA2530
      NII=NPP                                                           DATA2535
      GO TO 924                                                         DATA2540
  923 NII=I                                                             DATA2545
  924 DO 925 J=1,NPP                                                    DATA2550
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      IJ=NPST(J)                                                        DATA2555
      IF(IJ.EQ.NJ) GO TO 926                                            DATA2560
  925   CONTINUE                                                        DATA2565
    NPP=NPP+1                                                           DATA2570
    NPST(NPP)=NJ                                                        DATA2575
    NJJ=NPP                                                             DATA2580
    GO TO 928                                                           DATA2585
  926 NJJ=J                                                             DATA2590
  928 RP(NII)=RP(NII)+EI*FL/3.0+EJ*FL/6.0                               DATA2595
    RP(NJJ)=RP(NJJ)+EI*FL/6.0+EJ*FL/3.0                                 DATA2600
    EK=EJ                                                               DATA2605
    GO TO 910                                                           DATA2610
  930 IF (MP.GT.0) GO TO 940                                            DATA2615
    ISTOP=ISTOP+1                                                       DATA2620
    PRINT 15700                                                         DATA2625
  940 NPINC=IABS(NJ-NI)                                                 DATA2630
    NPMIN=MAX0(NPST(NPP),NPST(NPP-1))                                   DATA2635
    NPMAX=MIN0(NI,NJ)-1                                                 DATA2640
    DO 950 NK=NPMIN,NPMAX,NPINC                                         DATA2645
       NL=NK+NPINC                                                      DATA2650
       MP=MP+1                                                          DATA2655
       DX=X(NK)-X(NL)                                                   DATA2660
       DZ=Z(NK)-Z(NL)                                                   DATA2665
       FL= SQRT(DX*DX+DZ*DZ)                                              CDC
       PRINT 13500,NK,NL,FK,EK                                          DATA2675
       IF(MP.GT.1) GO TO 941                                            DATA2680
       NPP=NPP+1                                                        DATA2685
       NPST(NPP)=NK                                                     DATA2690
       NKK=NPP                                                          DATA2695
       NPP=NPP+1                                                        DATA2700
       NPST(NPP)=NL                                                     DATA2705
       NLL=NPP                                                          DATA2710
       GO TO 948                                                        DATA2715
  941  DO 942 K=1,NPP                                                   DATA2720
          KL=NPST(K)                                                    DATA2725
          IF(KL.EQ.NK) GO TO 943                                        DATA2730
  942     CONTINUE                                                      DATA2735
       NPP=NPP+1                                                        DATA2740
       NPST(NPP)=NK                                                     DATA2745
       NKK=NPP                                                          DATA2750
       GO TO 944                                                        DATA2755
  943  NKK=K                                                            DATA2760
  944  DO 945 L=1,NPP                                                   DATA2765
          KL=NPST(L)                                                    DATA2770
          IF(KL.EQ.NL) GO TO 946                                        DATA2775
  945     CONTINUE                                                      DATA2780
       NPP=NPP+1                                                        DATA2785
       NPST(NPP)=NL                                                     DATA2790
       NLL=NPP                                                          DATA2795
       GO TO 948                                                        DATA2800
  946  NLL=L                                                            DATA2805
  948  RP(NKK)=RP(NKK)+FK*EL/2.0                                        DATA2810
       RP(NLL)=RP(NLL)+FK*EL/2.0                                        DATA2815
  950  CONTINUE                                                         DATA2820
    GO TO 920                                                           DATA2825
  960 NSTN=NPP                                                          DATA2830
C                                                                       DATA2835
C  APPLY STEADY STATE OR TRANSIENT DIRICHLET BOUNDARY CONDITIONS TO     DATA2840
C  INITIAL CONDITIONS                                                   DATA2845
C                                                                       DATA2850
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 1000 IF (NBC.EQ.0) GO TO 1020                                          DATA2855
      DO 1010 NPP=1,NBC                                                 DATA2860
         NP=NN(NPP)                                                     DATA2865
 1010    H(NP)=HB(NPP)                                                  DATA2870
 1020 IF (ISTOP.EQ.0) GO TO 1030                                        DATA2875
      PRINT 15800, ISTOP                                                DATA2880
C                                                                       DATA2885
 1030 CONTINUE                                                          DATA2890
C                                                                       DATA2895
      PRINT 20000, NBN,(NPB(I),I=1,NBN)                                 DATA2900
      PRINT 21000, NBEL,(NBE(I),I=1,NBEL)                               DATA2905
      IF(NRSN.NE.0) PRINT 22000, NRSN,(NPRS(I),I=1,NRSN)                DATA2910
      IF(NRSEL.NE.0) PRINT 23000, NRSEL,(NRSE(I),I=1,NRSEL)             DATA2915
      IF(NST.NE.0) PRINT 26000, NST,NSTN,(NPST(I),I=1,NSTN)             DATA2920
      IF(NBC.NE.0) PRINT 27000, NBC,(NN(I),I=1,NBC)                     DATA2925
C                                                                       DATA2930
      RETURN                                                            DATA2935
C                                                                       DATA2940
C                                                                       DATA2945
10000 FORMAT(35H0INPUT TABLE 1.. BASIC PARAMETERS    // 5X,             DATA2950
     > 40H NUMBER OF NODAL POINTS. . . . . . . . . .,I5/ 5X,            DATA2955
     > 40H NUMBER OF ELEMENTS. . . . . . . . . . . .,I5/ 5X,            DATA2960
     > 40H NUMBER OF DIFFERENT MATERIALS . . . . . .,I5/ 5X,            DATA2965
     > 40H NUMBER OF CORRECTION MATERIALS. . . . . .,I5/ 5X,            DATA2970
     > 40H NUMBER OF TIME INCREMENTS . . . . . . . .,I5/ 5X,            DATA2975
     > 40H STEADY-STATE I.C. CONTROL . . . . . . . .,I5/ 5X,            DATA2980
     > 40H SOIL-PROPERTY CONTROL . . . . . . . . . .,I5/ 5X,            DATA2985
     > 40H NUMBER OF SOIL PARAMETERS . . . . . . . .,I5/ 5X,            DATA2990
     > 40H AUXILIARY STORAGE CONTROL . . . . . . . .,I5/ 5X,            DATA2995
     > 40H CONDUCTIVITY-PERMEABILITY CONTROL . . . .,I5/ 5X,            DATA3000
     > 40H GRAVITY CONTROL . . . . . . . . . . . . .,I5/ 5X,            DATA3005
     > 40H RESTART PARAMETER . . . . . . . . . . . .,I5/ 5X,            DATA3010
     > 40H MAXIMUM ITERATIONS PER CYCLE. . . . . . .,I5/ 5X,            DATA3015
     > 40H MAXIMUM CYCLES PER TIME STEP. . . . . . .,I5)                DATA3020
10001 FORMAT(1H ,4X,                                                    DATA3025
     > 40H LUMPING INDICATOR, ILUMP. . . . . . . . .,I5/ 5X,            DATA3030
     > 40H TIME-DIFFERENCE INDICATOR, IMID . . . . .,I5)                DATA3035
10100 FORMAT(5X,40H TIME INCREMENT. . . . . . . . . . . . . .,F10.6/ 5X, DATA3040
     > 40H MULTIPLIER FOR INCREASING DELT. . . . . .,F10.6/ 5X,         DATA3045
     > 40H MAXIMUM VALUE OF DELT . . . . . . . . . .,1PE10.4/ 5X,       DATA3050
     > 40H MAXIMUM VALUE OF TIME . . . . . . . . . .,1PE10.4/ 5X,       DATA3055
     > 40H DEGREES OF PRIN-AXIS INCLINATION. . . . .,0P,F10.6/ 5X,      DATA3060
     > 40H STEADY-STATE TOLERANCE. . . . . . . . . .,F10.6/ 5X,         DATA3065
     > 40H TRANSIENT STATE TOLERANCE ...............,F10.6/ 5X,         DATA3070
     > 40H DENSITY OF WATER. . . . . . . . . . . . .,F10.6/ 5X,         DATA3075
     > 40H ACCELERATION OF GRAVITY . . . . . . . . .,F10.3/ 5X,         DATA3080
     > 40H VISCOSITY OF WATER. . . . . . . . . . . .,F10.6/ 5X,         DATA3085
     > 40H TIME-INTEGRATION PARAMETER. . . . . . . .,F10.6)             DATA3090
10200 FORMAT(//6X,14HOUTPUT CONTROL)                                    DATA3095
10201 FORMAT(//6X,19HDISK OUTPUT CONTROL)                               DATA3100
10300 FORMAT(36H1INPUT TABLE 2.. MATERIAL PROPERTIES// 9H MAT. NO., 9(  DATA3105
     > 3A4))                                                            DATA3110
10400 FORMAT(53H1INPUT TABLE 3.. SOIL-PROPERTIES INTERPOLATION VALUES// DATA3115
     > 9H MAT. NO.,9X,8HPRESSURE,13X,16HMOISTURE CONTENT,4X,            DATA3120
     > 25HCONDUCTIVITY/PERMEABILITY,6X,14HWATER CAPACITY)               DATA3125
10500 FORMAT(44H1INPUT TABLE 3.. MOISTURE-CONTENT PARAMETERS//          DATA3130
     > 9H MAT. NO.,8(3A4))                                              DATA3135
10600 FORMAT(40H1INPUT TABLE 4.. CONDUCTIVITY PARAMETERS// 9H MAT. NO., DATA3140
     > 2(3A4))                                                          DATA3145
10700 FORMAT(32H1INPUT TABLE 5. NODAL POINT DATA//2X,                   DATA3150
     > 4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,        DATA3155
     > 10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ/                         DATA3160
     > 27H***************************,3X,27H***************************,DATA3165
     >3X,27H***************************,3X,27H***************************DATA3170
     >*/)                                                                 DATA3175
10800 FORMAT(29H1INPUT TABLE 6.. ELEMENT DATA// 11X,                      DATA3180
     > 31HGLOBAL INDICES OF ELEMENT NODES/7X,7HELEMENT,3X,1H1,7X,1H2,     DATA3185
     > 7X,1H3,7X,1H4,6X,8HMATERIAL,4X,10HNODE DIFF.)                      DATA3190
10900 FORMAT (64H CORRECTIONS TO MATERIAL TYPES AND CLASSES FOR SELECTEDDATA3195
     > ELEMENTS)                                                          DATA3200
11000 FORMAT(1H1,'INPUT TABLE',I3,' STEADY-STATE B. C. PARAMETERS'//5X, DATA3205
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . .,I5/ 5X,                DATA3210
     > 40H NUMBER OF SURFACE TERMS . . . . . . . .,I5/ 5X,                DATA3215
     > 40H NUMBER OF RAINFALL PROFILES . . . . . .,I5/ 5X,                DATA3220
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . .,I5/ 5X,                DATA3225
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . .,I5/ 5X,                DATA3230
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . .,I5)                    DATA3235
11100 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE B. C. OF ',             DATA3240
     > 9HFORM H=HB//6H  NODE,7X,2HHB)                                     DATA3245
11110 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT B. C. OF FORM H=HB'//      DATA3250
     > 6H  NODE,7X,2HHB)                                                  DATA3255
11200 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE SURFACE TERMS',         DATA3260
     > 33H F=EI AT NODE NI, E=EJ AT NODE NJ//8X,2HNI,8X,2HNJ,10X,2HEI,    DATA3265
     > 13X,2HEJ/)                                                         DATA3270
11210 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT SURFACE TERMS',            DATA3275
     > 33H F=EI AT NODE NI, E=EJ AT NODE NJ// 5H   NI,5H   NJ,6X,2HEI,    DATA3280
     > 12X,2HEJ/)                                                         DATA3285
11300 FORMAT(1H1,'INPUT TABLE',I3,' TRANSIENT B.C. PARAMETERS'//5X,       DATA3290
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . .,I5/ 5X,                DATA3295
     > 40H NUMBER OF SURFACE TERMS . . . . . . . .,I5/ 5X,                DATA3300
     > 40H NUMBER OF RAINFALL PROFILES . . . . . .,I5/ 5X,                DATA3305
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . .,I5/ 5X,                DATA3310
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . .,I5/ 5X,                DATA3315
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . .,I5)                    DATA3320
11400 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE RAINFALL DATA')         DATA3325
11410 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL DATA')            DATA3330
11500 FORMAT(/8H PROFILE,I5/8X,4HTIME,11X,4HRATE)                         DATA3335
11600 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY STATE RAINFALL DISTRIBUTION DATA3340
     >AND PONDING'//6X,4HNODE,6X,4HTYPE,5X,5HDEPTH)                       DATA3345
11610 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL DISTRIBUTION ANDDATA3350
     > PONDING'//6X,4HNODE,6X,4HTYPE,5X,5HDEPTH)                          DATA3355
11700 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE RAINFALL-SEEPAGE SURFADATA3360
     >CE INFORMATION'//5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)              DATA3365
11710 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL-SEEPAGE SURFACE DATA3370
     >INFORMATION'//5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)                 DATA3375
12000 FORMAT(16I5)                                                        DATA3380
12100 FORMAT(80I1)                                                        DATA3385
12200 FORMAT(10X,10I1)                                                    DATA3390
12300 FORMAT(8F10.0)                                                      DATA3395
12400 FORMAT(2(1PE15.4))                                                  DATA3400
12500 FORMAT(I8,1P9F12.4)                                                 DATA3405
12600 FORMAT(1P,I8,E19.4,3E25.4/(2X,4E25.4))                              DATA3410
12700 FORMAT(I8,9E12.4/(8X,9E12.4))                                       DATA3415
12800 FORMAT(I5,2F10.3)                                                   DATA3420
12900 FORMAT(1H,1P,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3)      DATA3425
13000 FORMAT(I10,4I8,I10,I13)                                             DATA3430
13100 FORMAT(I10,32X,I10,32X,I10)                                         DATA3435
13200 FORMAT(I5,1PE15.4)                                                  DATA3440
13300 FORMAT(2I5,2F10.0)                                                  DATA3445
13400 FORMAT(3I5,5X,2F10.0)                                               DATA3450
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13500 FORMAT(2I10,2(1PE15.4))                                               DATA3455
13600 FORMAT(I5,5X,F10.0)                                                   DATA3460
14300 FORMAT(////37H CHECK BOUNDARY CONDITIONS, MAXIMUM =,I5///)            DATA3465
14800 FORMAT(////43H TOO MANY RAINFALL-SEEPAGE NODES, MAXIMUM =,I5///)      DATA3470
14900 FORMAT(////34H ERROR IN SURFACE CARD FOR ELEMENT,I5///)               DATA3475
15000 FORMAT(////28H EXECUTION HALTED BECAUSE OF,I5,13H FATAL ERRORS///)DATA3480
15100 FORMAT(////30H ERROR IN NODAL-POINT CARD NO.,I5///)                   DATA3485
15200 FORMAT(////26H ERROR IN ELEMENT CARD NO.,I5///)                       DATA3490
15300 FORMAT(////36H ERROR IN INITIAL-CONDITION CARD NO.,I5///)             DATA3495
15400 FORMAT(////49H ERROR IN FIRST H=BB TYPE BOUNDARY-CONDITION CARD //DATA3500
    >  /)                                                                   DATA3505
15500 FORMAT(////48H ERROR IN FIRST RAINFALL-TYPE-PONDING-DEPTH CARD///)DATA3510
15600 FORMAT(////45H ERROR IN FIRST RAINFALL-SEEPAGE ELEMENT CARD///)   DATA3515
15700 FORMAT(////33H ERROR IN FIRST SURFACE-TERM CARD///)                   DATA3520
15800 FORMAT(////45H ASSEMBLY AND SOLUTION WILL NOT BE PERFORMED,,I5,     DATA3525
    > 19H  FATAL CARD ERRORS///)                                            DATA3530
15900 FORMAT(////40H ERROR IN MATERIAL TYPE CODE FOR ELEMENT,I5///)       DATA3535
20000 FORMAT(1H1,5X,'CHECK ALL BOUNDARY NODAL AND ELEMENT INFORMATION'//DATA3540
     > /5X,'TOTAL NUMBER OF BOUNDARY NODES =',I5/5X,                        DATA3545
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                                  DATA3550
21000 FORMAT(1H0,4X,'TOTAL NUMBER OF BOUNDARY ELEMENTS =',I5/5X,           DATA3555
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                                  DATA3560
22000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY NODES =',DATA3565
     > I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))                            DATA3570
23000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY ELEMENT =DATA3575
     > ',I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))                          DATA3580
26000 FORMAT(1H0,4X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY ELEMENTS =', DATA3585
     > I5/5X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY NODES =',I5/5X,         DATA3590
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                                  DATA3595
27000 FORMAT(1H0,4X,'TOTAL NUMBER OF DIRICHLET NODES =',I5/5X,              DATA3600
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                                  DATA3605
      END                                                                   DATA3610
      SUBROUTINE SURF(X,Z,IE, DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,                SURF 005
     > MAXNP,MAXEL, MAXBEL,MAXBNP)                                          SURF 010
C                                                                           SURF 015
C                                                                           SURF 020
C  FUNCTION OF SUBROUTINE--TO IDENTIFY BOUNDING SIDES THROUGH THE ARRAY SURF 025
C  ISB(MP,4), TO CALCULATE THEIR LENGTHS DLB(MP), AND TO DETERMINE THE  SURF 030
C  DIRECTION COSINES DCOSX(MP) AND DCOSZ(MP) OF THE OUTWARDLY DIRECTED  SURF 035
C  UNIT NORMAL VECTOR FOR EACH BOUNDARY ELEMENT NBE(MP).                    SURF 040
C                                                                           SURF 045
C                                                                           SURF 050
      IMPLICIT REAL  (A-H,O-Z)                                               CDC
C                                                                           SURF 060
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                               SURF 065
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),      SURF 070
     > ISB(MAXBEL,4),NPB(MAXBNP)                                            SURF 075
C                                                                           SURF 080
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                                 SURF 085
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR                       SURF 090
C                                                                           SURF 095
C  FIND SURFACE SIDES BY LOCATING NONDUPLICATED SIDES                       SURF 100
C                                                                           SURF 105
      NBEL=0                                                                SURF 110
      NBN=0                                                                 SURF 115
      DO 40 MI=1,NEL                                                        SURF 120
         DO 30 IQ=1,4                                                       SURF 125
            IQ1=IQ+1                                                        SURF 130
            IF (IQ.EQ.4) IQ1=1                                              SURF 135
            DO 20 MJ=1,NEL                                                  SURF 140
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               IF (MJ.EQ.MI) GO TO 20                                  SURF 145
               DO 10 JQ=1,4                                            SURF 150
                  JQ1=JQ+1                                             SURF 155
                  IF (JQ.EQ.4) JQ1=1                                   SURF 160
                  IF (IE(MI,IQ).EQ.IE(MJ,JQ).AND.IE(MI,IQ1).EQ.IE(MJ,  SURF 165
     >             JQ1)) GO TO 30                                      SURF 170
                  IF (IE(MI,IQ).EQ.IE(MJ,JQ1).AND.IE(MI,IQ1).EQ.IE(MJ, SURF 175
     >             JQ)) GO TO 30                                       SURF 180
   10             CONTINUE                                             SURF 185
   20          CONTINUE                                                SURF 190
C                                                                      SURF 195
            NI=IE(MI,IQ)                                               SURF 200
            NJ=IE(MI,IQ1)                                              SURF 205
            NBEL=NBEL+1                                                SURF 210
            NBE(NBEL)=MI                                               SURF 215
            ISB(NBEL,1)=NI                                             SURF 220
            ISB(NBEL,2)=NJ                                             SURF 225
            ISB(NBEL,3)=IQ                                             SURF 230
            ISB(NBEL,4)=IQ1                                            SURF 235
            IF(NBEL.GT.1) GO TO 25                                     SURF 240
            NBN=NBN+1                                                  SURF 245
            NPB(NBN)=NI                                                SURF 250
            NBN=NBN+1                                                  SURF 255
            NPB(NBN)=NJ                                                SURF 260
   25       DO 26 I=1,NBN                                              SURF 265
               IJ=NPB(I)                                               SURF 270
               IF(IJ.EQ.NI) GO TO 27                                   SURF 275
   26          CONTINUE                                                SURF 280
            NBN=NBN+1                                                  SURF 285
            NPB(NBN)=NI                                                SURF 290
   27       DO 28 J=1,NBN                                              SURF 295
               IJ=NPB(J)                                               SURF 300
               IF(IJ.EQ.NJ) GO TO 29                                   SURF 305
   28          CONTINUE                                                SURF 310
            NBN=NBN+1                                                  SURF 315
            NPB(NBN)=NJ                                                SURF 320
   29       CONTINUE                                                   SURF 325
   30       CONTINUE                                                   SURF 330
   40    CONTINUE                                                      SURF 335
C                                                                      SURF 340
C  CALCULATE SIDE LENGTHS AND DIRECTION COSINES                        SURF 345
C                                                                      SURF 350
      DO 70 MP=1,NBEL                                                  SURF 355
         M=NBE(MP)                                                     SURF 360
         NI=ISB(MP,1)                                                  SURF 365
         NJ=ISB(MP,2)                                                  SURF 370
C        DX=X(NI)-X(NJ)                                                SURF 375
C        DZ=Z(NI)-Z(NJ)                                                SURF 380
         DX=X(NJ)-X(NI)                                                SURF 385
         DZ=Z(NJ)-Z(NI)                                                SURF 390
         DLB(MP)= SQRT(DX*DX+DZ*DZ)                                      CDC
C                                                                      SURF 400
         BETA= ATAN2(DZ,DX)                                              CDC
         DCOSXB(MP)= SIN(BETA)                                           CDC
         DCOSZB(MP)=- COS(BETA)                                          CDC
   70    CONTINUE                                                      SURF 420
      RETURN                                                           SURF 425
      END                                                              SURF 430
      SUBROUTINE VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXBBP) VELT 005
C                                                                      VELT 010
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C  FUNCTION OF SUBROUTINE TO COMPUTE DARCY VELOCITY VX AND VZ            VELT 015
C                                                                         VELT 020
      IMPLICIT REAL  (A-H,O-Z)                                             CDC
C                                                                         VELT 030
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                             VELT 035
      DIMENSION C(MAXNP,MAXHBP),H(MAXNP),HT(MAXNP),VX(MAXNP),VZ(MAXNP),   VELT 040
     > AKX(MAXEL,4),AKZ(MAXEL,4)                                          VELT 045
C                                                                         VELT 050
      DIMENSION QQ(4,4),RQ(4),XQ(4),ZQ(4),HTQ(4),AKXQ(4),AKZQ(4)          VELT 055
C                                                                         VELT 060
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                               VELT 065
C                                                                         VELT 070
      IHALFB=(IBAND-1)/2                                                  VELT 075
      IHBP=IHALFB+1                                                       VELT 080
C                                                                         VELT 085
C  INITIAZE THE DARCY VELOCITY VX(NP) AND VZ(NP)                          VELT 090
C                                                                         VELT 095
      DO 100 NP=1,NNP                                                     VELT 100
      VX(NP)=0.0                                                          VELT 105
  100 VZ(NP)=0.0                                                          VELT 110
C                                                                         VELT 115
C  CALCULATE THE TOTAL HEAD HT(NP)                                        VELT 120
C                                                                         VELT 125
      DO 105 NP=1,NNP                                                     VELT 130
  105 HT(NP)=H(NP)-X(NP)*SNFE+Z(NP)*CSFE                                  VELT 135
C                                                                         VELT 140
C  COMPUTE DARCY VELOCITIES BY APPLYING FINITE ELEMENT METHOD TO DARCY    VELT 145
C  EQUATIONS.  IXZ=1 FOR COMPUTING VX, IXZ=2 FOR COMPUTING VZ.            VELT 150
C                                                                         VELT 155
C                                                                         VELT 160
      DO 300 IXZ=1,2                                                      VELT 165
C                                                                         VELT 170
C  INITIALIZE MATRIX C(NP,IB)                                             VELT 175
C                                                                         VELT 180
      DO 110 NP=1,NNP                                                     VELT 185
      DO 110 IB=1,IHBP                                                    VELT 190
  110 C(NP,IB)=0.0                                                        VELT 195
C                                                                         VELT 200
C  COMPUTE THE ELEMENT MATRIX QQ(IQ,JQ) AND RQ(IQ)                        VELT 205
C                                                                         VELT 210
      DO 180 M=1,NEL                                                      VELT 215
C                                                                         VELT 220
      DO 120 IQ=1,4                                                       VELT 225
      NP=IE(M,IQ)                                                         VELT 230
      XQ(IQ)=X(NP)                                                        VELT 235
      ZQ(IQ)=Z(NP)                                                        VELT 240
      HTQ(IQ)=HT(NP)                                                      VELT 245
      AKXQ(IQ)=AKX(M,IQ)                                                  VELT 250
  120 AKZQ(IQ)=AKZ(M,IQ)                                                  VELT 255
C                                                                         VELT 260
      CALL Q4D(QQ,RQ,XQ,ZQ,AKXQ,AKZQ,HTQ,SNFE,CSFE,IXZ)                   VELT 265
C                                                                         VELT 270
C                                                                         VELT 275
C  ASSEMBLE QQ(IQ,JQ) INTO THE GLOBAL MATRIX C(NP,IB) AND                 VELT 280
C  FORM THE LOAD VECTOR VX(NP) OR VZ(NP)                                  VELT 285
C                                                                         VELT 290
      DO 140 IQ=1,4                                                       VELT 295
      NI=IE(M,IQ)                                                         VELT 300
      DO 130 JQ=1,4                                                       VELT 305
      NJ=IE(M,JQ)                                                         VELT 310
      IF(NJ.LT.NI) GO TO 130
      IB=NJ-NI+1
      C(NI,IB)=C(NI,IB)+QQ(IQ,JQ)
  130 CONTINUE
C
      IF(IXZ.EQ.2) GO TO 135
      VX(NI)=VX(NI)+RQ(IQ)
      GO TO 140
  135 VZ(NI)=VZ(NI)+RQ(IQ)
  140 CONTINUE
C
  180 CONTINUE
C
C  SOLVE THE MATRIX EQUATION CX=B
C
      IF(IXZ.EQ.2) GO TO 200
      CALL BANSOL(1,C,VX,NNP,IHBP,MAXNP,MAXHBP)
      CALL BANSOL(2,C,VX,NNP,IHBP,MAXNP,MAXHBP)
      GO TO 300
  200 CALL BANSOL(1,C,VZ,NNP,IHBP,MAXNP,MAXHBP)
      CALL BANSOL(2,C,VZ,NNP,IHBP,MAXNP,MAXHBP)
  300 CONTINUE
C
      RETURN
      END
      SUBROUTINE Q4D(QQ,RQ,XQ,ZQ,AKXQ,AKZQ,HTQ,SNFE,CSFE,IND)
C
C
C  FUNCTION OF SUBROUTINE-TO EVALUATE THE MATRIX QUADRATURE OVER THE
C  AREA OF ONE ELEMENT.  THESE INTEGRALS ARISE THROUGH THE
C  APPLICATION OF THE GALERKIN INTEGRATION SCHEME
C
C
C
      IMPLICIT REAL    (A-H,O-Z)
      REAL    N(4)
C
      DIMENSION QQ(4,4),RQ(4),XQ(4),ZQ(4),HTQ(4),AKXQ(4),AKZQ(4)
      DIMENSION S(4),T(4),DNX(4),DNZ(4)
      DIMENSION PJAB(2,2),DNSS(4),DNTT(4)
C
      DATA P / 0.577350269189626 /, S / -1.0D+00, 1.0D+00, 1.0D+00,-
     > 1.0D+00 /, T / -1.0D+00,-1.0D+00, 1.0D+00, 1.0D+00 /
C
C  INITIALIZE MATRICES QQ(IQ,JQ) AND RQ(IQ)
C
      DO 100 IQ=1,4
      RQ(IQ)=0.0
      DO 100 JQ=1,4
  100 QQ(IQ,JQ)=0.0
C
C
C  SUMMATION OF THE INTEGRAND OVER THE GAUSSIAN POINTS
C
C
      DO 400 KG=1,4
C
C  DETERMINE LOCAL COORDINATE (SS,TT) OF
C  GAUSS-INTEGRATION POINT KG
C
      SS=P*S(KG)
      TT=P*T(KG)
C
C  CALCULATE VALUES OF THE BASIS FUNCTIONS N(IQ) AND THEIR DERIVATIVES
C  DNX(IQ) AND DNZ(IQ) WITH RESPECT TO X AND Z, RESPECTIVELY, AT
C  THE GAUSS POINT KG
C
            CALL BASE(N,DNSS,DNTT,SS,TT)
C
         DO 11 I=1,2
            DO 11 J=1.2
   11          PJAB(I,J)=0.0
         DO 12 I=1,4
            PJAB(1,1)=PJAB(1,1)+ZQ(I)*DNTT(I)
            PJAB(1,2)=PJAB(1,2)-ZQ(I)*DNSS(I)
            PJAB(2,1)=PJAB(2,1)-XQ(I)*DNTT(I)
   12       PJAB(2,2)=PJAB(2,2)+XQ(I)*DNSS(I)
         DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)
         DJACI=1.0/DJAC
         DO 13 I=1,2
            DO 13 J=1,2
   13          PJAB(I,J)=PJAB(I,J)*DJACI
         DO 14 I=1,4
            DNX(I)=DNSS(I)*PJAB(1,1)+DNTT(I)*PJAB(1,2)
   14       DNZ(I)=DNSS(I)*PJAB(2,1)+DNTT(I)*PJAB(2,2)
C
      AKXK=0.0
      AKZK=0.0
C
C  ACCUMULATE THE SUMS TO OBTAIN THE MATRIX INTEGRALS QQ(IQ,JQ)
C  AND RQ(IQ)
C
      DO 150 IQ=1,4
      AKXK=AKXK+AKXQ(IQ)*N(IQ)
  150 AKZK=AKZK+AKZQ(IQ)*N(IQ)
      DO 300 IQ=1,4
      DO 300 JQ=1,4
      QQ(IQ,JQ)=QQ(IQ,JQ)+ N(IQ)*N(JQ)*DJAC
      IF(IND.EQ.2) GO TO 200
      RQ(IQ)=RQ(IQ)-AKXK*N(IQ)*(HTQ(JQ)*DNX(JQ))*DJAC
      GO TO 300
  200 RQ(IQ)=RQ(IQ)-AKZK*N(IQ)*(HTQ(JQ)*DNZ(JQ))*DJAC
  300 CONTINUE
  400 CONTINUE
      RETURN
      END
      SUBROUTINE SPROP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,
     > CAPROP,  MAXEL,MAXNP, MAXMAT,        MXSPPM, NEI,KSP)
C
C
C  FUNCTION OF SUBROUTINE--TO CALCULATE SOIL PROPERTIES, I.E. THE
C  WATER CONTENTS TH(M,IQ), WATER CAPACITIES DTH(M,IQ), AND
C  PRINCIPAL VALUES OF THE CONDUCTIVITY TENSOR AKX(M,IQ) AND AKZ(M,IQ).
C
C
      IMPLICIT REAL  (A-H,O-Z)
C
      DIMENSION IE(MAXEL,5),H(MAXNP),TH(MAXEL,4),DTH(MAXEL,4),
     > AKX(MAXEL,4),AKZ(MAXEL,4)
C
      DIMENSION PROP(MAXMAT,5),THPROP(MAXMAT,MXSPPM),
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),
     > CAPROP(MAXMAT,MXSPPM)
C
      COMMON /MIL/ NMAT,NMPPM,NSPPM
C
C
C
C -------- TH, DTH/DH, AKX, AND AKZ ARE OBTAINED BY TABLE
C
      IF(KSP.EQ.0) GO TO 80
      DO 70 M=1,NEL
         MTYP=IE(M,5)
         SATKX=PROP(MTYP,4)
         SATKZ=PROP(MTYP,5)
         DO 60 IQ=1,4
            NP=IE(M,IQ)
            HNP=H(NP)
            IF (HNP.GT.HPROP(MTYP,1)) GO TO 10
            JL=1
            JU=2
            A=0.
            GO TO 50
   10       IF (HNP.LT.HPROP(MTYP,NSPPM)) GO TO 20
            JL=NSPPM
            JU=1
            A=0.
            GO TO 50
   20       DO 30 J=2,NSPPM
               JU=J
               IF (HPROP(MTYP,J).GT.HNP) GO TO 40
   30          CONTINUE
   40       JL=JU-1
            A=(HNP-HPROP(MTYP,JL))/(HPROP(MTYP,JU)-HPROP(MTYP,JL))
   50       TH(M,IQ)=THPROP(MTYP,JL)+A*(THPROP(MTYP,JU)-THPROP(MTYP,JL))
            DTH(M,IQ)=CAPROP(MTYP,JL)+A*(CAPROP(MTYP,JU)-CAPROP(MTYP,JL)
     >         )
            USKFCT=AKPROP(MTYP,JL)+A*(AKPROP(MTYP,JU)-AKPROP(MTYP,JL))
            AKX(M,IQ)=SATKX*USKFCT
            AKZ(M,IQ)=SATKZ*USKFCT
   60    CONTINUE
   70 CONTINUE
      RETURN
C
C ------- TH, DTH/DH, AKX, AND AKZ ARE OBTAINED BY ANALYTICAL FORM
C ------- THE READER MUST SUPPLY THE FUNCTIONAL FORM OF FKX, FKZ, AND
C ------- FTH BELOW
C
   80 DO 95 M=1,NEL
         MTYP=IE(M,5)
         SATKX=PROP(MTYP,4)
         SATKZ=PROP(MTYP,5)
C
C ------- WCR= THPROP(MTYP,1)=0.065, 0.050 FOR TWO SAMPLE MATERUALS
C ------- WCS=THPROP(MTYP,2)=0.364, 0.341 FOR TWO SAMPLE MATERIALS
C ------- RN=THPROP(MTYP,3)=1.092217, 1.546937 FOR TWO SAMPLE MATERIALS
C ------- ALPH=THPROP(MTYP,4)=0.109, 0.002166 FOR TWO SAMPLE MATERIALS
C
         WCR=THPROP(MTYP,1)
         WCS=THPROP(MTYP,2)
         RN=THPROP(MTYP,3)
      ALPH=THPROP(MTYP,4)                                               SPRO 380
      RM=1.0D0-1.0D0/RN                                                 SPRO 385
      DO 90 IQ=1,4                                                      SPRO 390
         NP=IE(M,IQ)                                                    SPRO 395
         HNP=H(NP)                                                      SPRO 400
         HNP=-HNP                                                       SPRO 405
C                                                                       SPRO 410
C                                                                       SPRO 415
C ------- SATURATED CONDITION                                           SPRO 420
C                                                                       SPRO 425
         IF(HNP.GT.0.0) GO TO 85                                        SPRO 430
         TH(M,IQ)=WCS                                                   SPRO 435
         DTH(M,IQ)=0.0D0                                                SPRO 440
         AKX(M,IQ)=SATKX                                                SPRO 445
         AKZ(M,IQ)=SATKZ                                                SPRO 450
         GO TO 90                                                       SPRO 455
C                                                                       SPRO 460
C ------- UNSATURATED CASE                                              SPRO 465
C                                                                       SPRO 470
  85     THMIQ=WCR+(WCS-WCR)/(1.0D0+(ALPH*HNP)**RN)**RM                 SPRO 475
         TH(M,IQ)=THMIQ                                                 SPRO 480
         RWC=(THMIQ-WCR)/(WCS-WCR)                                      SPRO 485
         TERM=(1.0-RWC**(1.0/RM))**RM                                   SPRO 490
         RK= SQRT(RWC)*(1.0-TERM)*(1.-TERM)                              CDC
         AKX(M,IQ)=SATKX*RK                                             SPRO 500
         AKZ(M,IQ)=SATKZ*RK                                             SPRO 505
         DTH(M,IQ)=ALPH*(RN-1.0)*TERM*RWC**(1.0/RM)                     SPRO 510
C                                                                       SPRO 515
  90     CONTINUE                                                       SPRO 520
  95 CONTINUE                                                           SPRO 525
      RETURN                                                            SPRO 530
      END                                                               SPRO 535
      SUBROUTINE BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,   BCPR 005
     > HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,MAXNP,  BCPR 010
     > MXRSEL,MXRSNP,                    TIME,NCHG)                     BCPR 015
C                                                                       BCPR 020
C                                                                       BCPR 025
C  FUNCTION OF SUBROUTINE--TO PREPARE BOUNDARY CONDITIONS FOR THE       BCPR 030
C  RAINFALL-SEEPAGE NODES.  IF THE PRESSURE H(NP) BECOMES GREATER THAN  BCPR 035
C  THE PUDDLING DEPTH HCON(NP), THEN THE RAINFALL RATE IS GREATER       BCPR 040
C  THAN THAT WHICH CAN BE ABSORBED BY THE SOIL AND EITHER INWARD FLUX   BCPR 045
C  CONTINUES AT A REDUCED RATE OR SEEPAGE, OUTWARD FLUX, BEGINS.        BCPR 050
C  IN EITHER EVENT THE BOUNDARY CONDITION IS CHANGED TO THE             BCPR 055
C  CONSTANT PUDDLING DEPTH HCON(NP).  ON THE OTHER HAND, SHOULD THE     BCPR 060
C  INTERIOR DARCY FLUX DCYFLX(NP) BECOME GREATER THAN CAN BE MAINTAINED BCPR 065
C  BY THE EXTERNAL FLUX, A CHANGE TO A FLUX BOUNDARY CONDITION IS       BCPR 070
C  EFFECTED.                                                            BCPR 075
C                                                                       BCPR 080
C                                                                       BCPR 085
C                                                                       BCPR 090
      IMPLICIT REAL    (A-H,O-Z)                                         CDC
C                                                                       BCPR 100
      DIMENSION IE(MAXEL,5),H(MAXNP),VX(MAXNP),VZ(MAXNP)                BCPR 105
C                                                                       BCPR 110
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),DCYFLX(MXRSNP),  BCPR 115
     > FLX(MXRSNP),RSFLX(MXRSNP),HCON(MXRSNP),NRSF(MXRSEL),             BCPR 120
     > IS(MXRSEL,4),NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP),           BCPR 125
     > IRFTYP(MXRSNP)                                                    CDC
      DIMENSION TRF(3,20),RF(3,20),RFALL(3)                              CDC
C                                                                       BCPR 135
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      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,THAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
C
C  CALCULATE THE RAINFALL RFALL(I) FROM EACH PROFILE
C
      IF (NRFPR.EQ.0) GO TO 40
      DO 30 I=1,NRFPR
         DO 20 J=2,NRFPAR
            IF (TRF(I,J-1).LE.TIME.AND.TIME.LE.TRF(I,J)) GO TO 10
            GO TO 20
10          RFALL(I)=RF(I,J-1)+(TIME-TRF(I,J-1))*(RF(I,J)-RF(I,J-1))/
    >        (TRF(I,J)-TRF(I,J-1))
            GO TO 30
20       CONTINUE
30    CONTINUE
C
C  DETERMINE THE NORMAL RAINFALLS FLX(NP) AND DARCY FLUXES DCYFLX(NP)
C  FOR EACH RAINFALL-SEEPAGE NODAL POINT
C
40    DO 50 NP=1,NRSN
         FLX(NP)=0.
50       DCYFLX(NP)=0.
      DO 70 MP=1,NRSEL
         M=NRSE(MP)
         NI=IS(MP,1)
         NJ=IS(MP,2)
         DO 60 I=1,NRSN
            IJ=NPRS(I)
            IF(IJ.NE.NI) GO TO 60
            NII=I
            GO TO 62
60       CONTINUE
62       DO 65 J=1,NRSN
            IJ=NPRS(J)
            IF(IJ.NE.NJ) GO TO 65
            NJJ=J
            GO TO 67
65       CONTINUE
67       CONTINUE
         NITYP=IRFTYP(NII)
         NJTYP=IRFTYP(NJJ)
         RFNI=0.
         RFNJ=0.
         IF (NITYP.GT.0) RFNI=RFALL(NITYP)
         IF (NJTYP.GT.0) RFNJ=RFALL(NJTYP)
C
C  OBTAIN RAINFALL RATES RFNI AND RFNJ AT POINTS NI AND NJ NORMAL TO
C  THE SIDE SUBTENDED BY THESE POINTS
C
         MTYP=IE(M,5)
         PROJ=-DCOSX(MP)*SNFE+DCOSZ(MP)*CSFE
         RFNI=-RFNI*PROJ
         RFNJ=-RFNJ*PROJ
C
C  CALCULATE RAINFALL FLUX PASSING THROUGH SIDE (NI,NJ) AND DIVIDE IT
C  INTO TWO PARTS FLX(NI) AND FLX(NJ).  PERFORM A SIMILAR OPERATION TO
C  OBTAIN DARCY FLUXES DCYFLX(NI) AND DCYFLX(NJ)
C
         FLX(NII)=FLX(NII)+RFNI*DL(MP)/3.0+RFNJ*DL(MP)/6.0
         FLX(NJJ)=FLX(NJJ)+RFNI*DL(MP)/6.0+RFNJ*DL(MP)/3.0
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C                                                                       BCPR 440
C     COMPUTE THE FLUX THROUGH POINT NI USING THE WHOLE BOUNDARY LENGTH BCPR 445
C     AND THE FLUX THROUGH POINT NJ USING THE WHOLE BOUNDARY SIDE LENGTHBCPR 450
C                                                                       BCPR 455
            FNI=(VX(NI)*DCOSX(MP)+VZ(NI)*DCOSZ(MP))*DL(MP)              BCPR 460
            FNJ=(VX(NJ)*DCOSX(MP)+VZ(NJ)*DCOSZ(MP))*DL(MP)              BCPR 465
C                                                                       BCPR 470
C     DISTRIBUTE THE ABOVE FLUXES TO TWO END POINTS OF THE SIDE         BCPR 475
C                                                                       BCPR 480
C                                                                       BCPR 485
            DCYFLX(NII)=DCYFLX(NII)+FNI/3.0+FNJ/6.0                     BCPR 490
            DCYFLX(NJJ)=DCYFLX(NJJ)+FNJ/3.0+FNI/6.0                     BCPR 495
C                                                                       BCPR 500
   70       CONTINUE                                                    BCPR 505
C                                                                       BCPR 510
C     CHANGE TO FLUX OR CONSTANT-HEAD CONDITIONS, AS NECESSARY, AND SO  BCPR 515
C     INDICATE IN THE ARRAYS NPFLX(NPP) AND NPCON(NPP)                  BCPR 520
C                                                                       BCPR 525
         IF (NCHG.NE.(-1)) GO TO 80                                     BCPR 530
         NCHG=0                                                         BCPR 535
         RETURN                                                         BCPR 540
   80    NCHG=0                                                         BCPR 545
         DO 100 NPP=1,NRSN                                              BCPR 550
C                                                                       BCPR 555
C     CHECK IF THE CHANGING FROM RAINFALL-FLUX (NEUMANN) CONDITTION TO  BCPR 560
C     PONDING (DIRICHLET) CONDITTION IS NECESSARY                       BCPR 565
C                                                                       BCPR 570
            NP=NPFLX(NPP)                                               BCPR 575
            IF (NP.EQ.0) GO TO 90                                       BCPR 580
            IF(HCON(NPP).GE.H(NP)) GO TO 100                            BCPR 585
            NPCON(NPP)=NPFLX(NPP)                                       BCPR 590
            NPFLX(NPP)=0                                                BCPR 595
            NCHG=NCHG+1                                                 BCPR 600
            GO TO 100                                                   BCPR 605
C                                                                       BCPR 610
C     CHECK IF THE CHANGING FROM PONDING (DIRICHLET) CONDITTION TO      BCPR 615
C     RAINFALL-FLUX (NEUMANN) CONDITTION IS NECESSARY                   BCPR 620
C                                                                       BCPR 625
   90       NP=NPCON(NPP)                                               BCPR 630
            IF(FLX(NPP).LE.DCYFLX(NPP)) GO TO 100                       BCPR 635
            NPFLX(NPP)=NPCON(NPP)                                       BCPR 640
            NPCON(NPP)=0                                                BCPR 645
            NCHG=NCHG+1                                                 BCPR 650
  100       CONTINUE                                                    BCPR 655
         RETURN                                                         BCPR 660
         END                                                            BCPR 665
         SUBROUTINE ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,       ASEM 005
        > MAXNP,MAXEL,MAXHBP, MAXMAT,          KSS,W,DELT)              ASEM 010
C                                                                       ASEM 015
C                                                                       ASEM 020
C     FUNCTION OF SUBROUTINE--TO ASSEMBLE THE TOTAL COEFFICIENT MATRIX  ASEM 025
C     C(NP,IB) AND LOAD VECTOR R(NP) FROM THE ELEMENT MATRICES QA(IQ,JQ),ASEM 030
C     QB(IQ,JQ), AND RQ(IQ).                                            ASEM 035
C                                                                       ASEM 040
C                                                                       ASEM 045
         IMPLICIT REAL  (A-H,O-Z)                                        CDC
C                                                                       ASEM 055
         DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                        ASEM 060
         DIMENSION C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP),HP(MAXNP),         ASEM 065
        > TH(MAXEL,4),DTH(MAXEL,4),AKX(MAXEL,4),AKZ(MAXEL,4)            ASEM 070
```

```
      DIMENSION PROP(MAXMAT,5)                                          CDC
C
      DIMENSION QA(4,4),QB(4,4),RQ(4),THQ(4),DTHQ(4),AKXQ(4),AKZQ(4),
     > XQ(4),ZQ(4),IEM(4)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /Q4PAR/ ALP,BETAP,POR,SINFE,COSFE
      COMMON /OPT/ ILUMP,IMID
C
      SINFE=SNFE
      COSFE=CSFE
      IHALFB=(IBAND-1)/2
      IHBP=IHALFB+1
C
      DELTI=1./DELT
      W1=W
      W2=1.-W
      IF (KSS.GT.0) GO TO 10
      DELTI=0.
      W1=1.
      W2=0.
C
C   INITIALIZE MATRICES C(NP,IB) AND R(NP)
C
   10 DO 20 NP=1,NNP
         R(NP)=0.0
         DO 20 IB=1,IHBP
   20       C(NP,IB)=0.0
C
C   START TO ASSEMBLE OVER ALL ELEMENTS
C
      DO 60 M=1,NEL
C
C   COMPUTE MATRICES QA(IQ,JQ), QB(IQ,JQ), AND RQ(IQ) FOR ELEMENT M
C
         MTYP=IE(M,5)
         ALP=PROP(MTYP,1)
         BETAP=PROP(MTYP,2)
         POR=PROP(MTYP,3)
         DO 30 IQ=1,4
            NP=IE(M,IQ)
            IEM(IQ)=NP
            XQ(IQ)=X(NP)
            ZQ(IQ)=Z(NP)
            THQ(IQ)=TH(M,IQ)
            DTHQ(IQ)=DTH(M,IQ)
            AKXQ(IQ)=AKX(M,IQ)
   30       AKZQ(IQ)=AKZ(M,IQ)
C
         CALL Q4(QA,QB,RQ,THQ,DTHQ,AKXQ,AKZQ,XQ,ZQ)
C
C
C   ASSEMBLE QA(IQ,JQ) AND QB(IQ,JQ) INTO THE TOTAL MATRIX
C   C(NP,IB) = B + A/DELT AND FORM THE LOAD VECTOR R(NP).
C   SINCE C IS SYMMETRIC, ONLY THE UPPER HALF BAND IS STORED
C
         IF(IMID.EQ.1) GO TO 51
   40    DO 50 IQ=1,4
            NI=IEM(IQ)
            R(NI)=R(NI)-RQ(IQ)
            DO 50 JQ=1,4                                                ASEM 375
               NJ=IEM(JQ)                                               ASEM 380
               QA(IQ,JQ)=QA(IQ,JQ)*DELTT                                ASEM 385
               R(NI)=R(NI)+(QA(IQ,JQ)-W2*QB(IQ,JQ))*HP(NJ)              ASEM 390
               IF (NJ.LT.NI) GO TO 50                                   ASEM 395
               IB=NJ-NI+1                                               ASEM 400
               C(NI,IB)=C(NI,IB)+QA(IQ,JQ)+W1*QB(IQ,JQ)                 ASEM 405
   50          CONTINUE                                                 ASEM 410
         GO TO 60                                                       ASEM 415
C                                                                       ASEM 420
   51    DO 53 IQ=1,4                                                   ASEM 425
            NI=IEM(IQ)                                                  ASEM 430
            R(NI)=R(NI)-RQ(IQ)                                          ASEM 435
            DO 52 JQ=1,4                                                ASEM 440
               NJ=IEM(JQ)                                               ASEM 445
               QA(IQ,JQ)=2.0D0*QA(IQ,JQ)*DELTT                          ASEM 450
               R(NI)=R(NI) + QA(IQ,JQ)*HP(NJ)                           ASEM 455
               IF(NJ.LT.NI) GO TO 52                                    ASEM 460
               IB=NJ-NI+1                                               ASEM 465
               C(NI,IB)=C(NI,IB)+QA(IQ,JQ)+QB(IQ,JQ)                    ASEM 470
   52          CONTINUE                                                 ASEM 475
   53       CONTINUE                                                    ASEM 480
   60    CONTINUE                                                       ASEM 485
      RETURN                                                            ASEM 490
      END                                                               ASEM 495
      SUBROUTINE Q4(QA,QB,RQ,THQ,DTHQ,AKXQ,AKZQ,XQ,ZQ)                  Q4   005
C                                                                       Q4   010
C                                                                       Q4   015
C  FUNCTION OF SUBROUTINE--TO EVALUATE THE MATRIX QUADRATURES OVER THE  Q4   020
C  AREA OF ONE ELEMENT OF WATER CONTENT AND COMPRESSIBILITY QA(IQ,JQ)   Q4   025
C  AND OF CONDUCTIVITY QB(IQ,JQ) AND RQ(IQ), THE LATTER ARISING FROM THEQ4   030
C  GRAVITY TERM IN THE MOISTURE-FLOW EQUATION. THESE INTEGRALS ARISE    Q4   035
C  THROUGH APPLICATION OF THE GALERKIN INTEGRATION SCHEME.              Q4   040
C                                                                       Q4   045
C                                                                       Q4   050
      IMPLICIT REAL    (A-H,O-Z)                                          CDC
      REAL    N(4)                                                        CDC
C                                                                       Q4   065
      COMMON /Q4PAR/ ALP,BETAP,POR,SNFE,CSFE                            Q4   070
      COMMON /OPT/ ILUMP,IMID                                           Q4   075
C                                                                       Q4   080
      DIMENSION QA(4,4),QB(4,4),RQ(4),THQ(4),DTHQ(4),AKXQ(4),AKZQ(4),   Q4   085
     > XQ(4),ZQ(4)                                                      Q4   090
      DIMENSION S(4),T(4),DNX(4),DNZ(4)                                 Q4   095
      DIMENSION PJAB(2,2),DNSS(4),DNTT(4)                               Q4   100
C                                                                       Q4   105
      DATA P / 0.577350269189626 /, S / -1.0D+00, 1.0D+00, 1.0D+00,-    Q4   110
     > 1.0D+00 /, T / -1.0D+00,-1.0D+00, 1.0D+00, 1.0D+00 /             Q4   115
C                                                                       Q4   120
C  INITIALIZE MATRICES QA, QB, AND RQ                                   Q4   125
C                                                                       Q4   130
      DO 10 IQ=1,4                                                      Q4   135
         RQ(IQ)=0.                                                      Q4   140
         DO 10 JQ=1,4                                                   Q4   145
            QB(IQ,JQ)=0.0                                               Q4   150
   10       QA(IQ,JQ)=0.0                                               Q4   155
C                                                                       Q4   160
      DO 40 KG=1,4                                                      Q4   165
C                                                                       Q4   170
C  DETERMINE LOCAL COORDINATES (SS,TT) OF GAUSS-INTEGRATION POINT KG    Q4   175
```

```
C
        SS = P*S(KG)
        TT = P*T(KG)
C
C  CALCULATE VALUES OF THE BASIS FUNCTIONS N(IQ) AND THEIR DERIVATIVES
C  DNX AND DNZ W.R.T X AND Z, RESPECTIVELY, AT THE GAUSS POINT KG
C
        CALL BASE(N,DNSS,DNTT,SS,TT)
C
C
        DO 11 I=1,2
           DO 11 J=1,2
   11         PJAB(I,J)=0.0
        DO 12 I=1,4
           PJAB(1,1)=PJAB(1,1)+ZQ(I)*DNTT(I)
           PJAB(1,2)=PJAB(1,2)-ZQ(I)*DNSS(I)
           PJAB(2,1)=PJAB(2,1)-XQ(I)*DNTT(I)
   12      PJAB(2,2)=PJAB(2,2)+XQ(I)*DNSS(I)
        DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)
        DJACI=1.0/DJAC
        DO 13 I=1,2
           DO 13 J=1,2
   13         PJAB(I,J)=PJAB(I,J)*DJACI
        DO 14 I=1,4
           DNX(I)=DNSS(I)*PJAB(1,1)+DNTT(I)*PJAB(1,2)
   14      DNZ(I)=DNSS(I)*PJAB(2,1)+DNTT(I)*PJAB(2,2)
C
        AKXQP=0.
        AKZQP=0.
        THQP=0.
        DTHQP=0.
C
C  ACCUMULATE THE SUMS TO EVALUATE THE MATRIX INTEGRALS QA(IQ,JQ),
C  QB(IQ,JQ), AND RQ(IQ)
C
        DO 20 IQ=1,4
           AKXQP=AKXQP+AKXQ(IQ)*N(IQ)
           AKZQP=AKZQP+AKZQ(IQ)*N(IQ)
           THQP=THQP+THQ(IQ)*N(IQ)
   20      DTHQP=DTHQP+DTHQ(IQ)*N(IQ)
        FHP=ALP*THQP/POR+BETAP*THQP+DTHQP
        AKXQP=AKXQP*DJAC
        AKZQP=AKZQP*DJAC
        FHP=FHP*DJAC
        DO 30 IQ=1,4
           RQ(IQ)=RQ(IQ)-DNX(IQ)*AKXQP*SNFE+DNZ(IQ)*AKZQP*CSFE
           DO 30 JQ=1,4
              QA(IQ,JQ)=QA(IQ,JQ)+FHP*N(IQ)*N(JQ)
              QB(IQ,JQ)=QB(IQ,JQ)+DNX(IQ)*AKXQP*DNX(JQ) +
    >                   DNZ(IQ)*AKZQP*DNZ(JQ)
   30         CONTINUE
   40   CONTINUE
     IF(ILUMP.NE.0) GO TO 50
C
     RETURN
   50 CONTINUE
     DO 52 I=1,4
        SUM=0.0
        DO 52 J=1,4
           SUM=SUM+QA(I,J)
```

```
 51          QA(I,J)=0.0                                                Q4    480
          QA(I,I)=SUM                                                   Q4    485
 52       CONTINUE                                                      Q4    490
      RETURN                                                            Q4    495
      END                                                               Q4    500
      SUBROUTINE BASE(N,DNSS,DNTT,SS,TT)                                BASE 005
C                                                                       BASE 010
C  FUNCTION OF THE SUBROUTINE-TO COMPUTE THE VALUES OF BASIS FUNCTIONS  BASE 015
C                                                                       BASE 020
C                                                                       BASE 025
      IMPLICIT REAL   (A-H,O-Z)                                          CDC
      REAL   N(4)                                                        CDC
C                                                                       BASE 040
      DIMENSION DNSS(4),DNTT(4)                                         BASE 045
C                                                                       BASE 050
      SM=1.0-SS                                                         BASE 055
      SP=1.0+SS                                                         BASE 060
      TM=1.0-TT                                                         BASE 065
      TP=1.0+TT                                                         BASE 070
      N(1)=0.25*SM*TM                                                   BASE 075
      N(2)=0.25*SP*TM                                                   BASE 080
      N(3)=0.25*SP*TP                                                   BASE 085
      N(4)=0.25*SM*TP                                                   BASE 090
      DNSS(1)=-0.25*TM                                                  BASE 095
      DNSS(2)=0.25*TM                                                   BASE 100
      DNSS(3)=0.25*TP                                                   BASE 105
      DNSS(4)=-0.25*TP                                                  BASE 110
      DNTT(1)=-0.25*SM                                                  BASE 115
      DNTT(2)=-0.25*SP                                                  BASE 120
      DNTT(3)=0.25*SP                                                   BASE 125
      DNTT(4)=0.25*SM                                                   BASE 130
      RETURN                                                            BASE 135
      END                                                               BASE 140
      SUBROUTINE BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST, BB,NN,          BC    005
     > MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXBCN, KSS)                         BC    010
C                                                                       BC    015
C                                                                       BC    020
C  FUNCTION OF SUBROUTINE--TO APPLY BOTH CONSTANT AND TIME-VARYING      BC    025
C  (RAINFALL-SEEPAGE) FLUX-TYPE NEUMANN AND PRESSURE-TYPE DIRICHLET     BC    030
C  BOUNDARY CONDITIONS.                                                 BC    035
C                                                                       BC    040
C                                                                       BC    045
      IMPLICIT REAL  (A-H,O-Z)                                           CDC
C                                                                       BC    055
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP)                                BC    060
      DIMENSION FLX(MXRSNP),HCON(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP)    BC    065
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)           BC    070
C                                                                       BC    075
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                             BC    080
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR                   B3    085
      COMMON /BCST/ NBC,NST,NSTN                                        BC    090
C                                                                       BC    095
      IHALFB=(IBAND-1)/2                                                BC    100
      IHBP=IHALFB+1                                                     BC    105
      IF (NBC.EQ.0) GO TO 90                                            BC    110
C                                                                       BC    115
C  APPLY CONSTANT DIRICHLET BOUNDARY CONDITIONS                         BC    120
C                                                                       BC    125
      DO 80 NPP=1,NBC                                                   BC    130
C                                                                       BC    135
```

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```
C   MODIFY LOAD VECTOR FOR NON-ZERO BB
C
          NI=NN(NPP)
          IF (BB(NPP).EQ.0.0) GO TO 40
          DO 10 IB=1,IHALFB
             NJ=NI-IB
             IF (NJ.LT.1) GO TO 20
             JB=IB+1
   10        R(NJ)=R(NJ)-BB(NPP)*C(NJ,JB)
   20     DO 30 IB=1,IHALFB
             NJ=NI+IB
             IF (NJ.GT.NNP) GO TO 40
             JB=IB+1
   30        R(NJ)=R(NJ)-BB(NPP)*C(NI,JB)
   40     R(NI)=BB(NPP)
C
C   ZERO COLUMN NN
C
          DO 50 IB=1,IHALFB
             NJ=NI-IB
             IF (NJ.LT.1) GO TO 60
             JB=IB+1
   50        C(NJ,JB)=0.0
C
C   MODIFY ROW NN
C
   60     DO 70 KB=1,IHBP
   70        C(NI,KB)=0.0
          C(NI,1)=1.0
   80     CONTINUE
C
C   MODIFY LOAD VECTOR FOR CONSTANT SURFACE TERMS OF THE FORM DR/DN=C
C
   90 IF (NST.EQ.0) GO TO 110
       DO 100 NPP=1,NSTN
          NP=NPST(NPP)
  100     R(NP)=R(NP)-RP(NPP)
  110 IF (NRSN.EQ.0) GO TO 210
C
C   APPLY DIRICHLET TIME-VARIABLE (RAINFALL-SEEPAGE) CONDITIONS
C
       DO 190 NPP=1,NRSN
C
C   MODIFY LOAD VECTOR FOR NON-ZERO HCON
C
          NI=NPCON(NPP)
          IF (NI.EQ.0) GO TO 190
          IF (HCON(NI).EQ.0.0) GO TO 150
          DO 120 IB=1,IHALFB
             NJ=NI-IB
             IF (NJ.LT.1) GO TO 130
             JB=IB+1
  120        R(NJ)=R(NJ)-HCON(NPP)*C(NJ,JB)
  130     DO 140 IB=1,IHALFB
             NJ=NI+IB
             IF (NJ.GT.NNP) GO TO 150
             JB=IB+1
  140        R(NJ)=R(NJ)-HCON(NPP)*C(NI,JB)
  150     R(NI)=HCON(NPP)
C
```

```
C   ZERO COLUMN NPCON                                                   BC   440
C                                                                       BC   445
          DO 160 IB=1,IHALFB                                            BC   450
             NJ=NI-IB                                                   BC   455
             IF (NJ.LT.1) GO TO 170                                     BC   460
             JB=IB+1                                                    BC   465
  160        C(NJ,JB)=0.0                                               BC   470
C                                                                       BC   475
C   MODIFY ROW NPCON                                                    BC   480
C                                                                       BC   485
  170     DO 180 KB=1,IHBP                                              BC   490
  180        C(NI,KB)=0.0                                               BC   495
          C(NI,1)=1.0                                                   BC   500
  190     CONTINUE                                                      BC   505
C                                                                       BC   510
C   APPLY NEUMANN TIME-VARIABLE (RAINFALL-SEEPAGE) CONDITIONS           BC   515
C                                                                       BC   520
       DO 200 NPP=1,NRSN                                                BC   525
          NP=NPFLX(NPP)                                                 BC   530
          IF (NP.EQ.0) GO TO 200                                        BC   535
          R(NP)=R(NP)-FLX(NPP)                                          BC   540
  200     CONTINUE                                                      BC   545
  210 RETURN                                                            BC   550
      END                                                               BC   555
      SUBROUTINE BANSOL(KKK,C,R,NNP,IHBP,MAXNP,MAXHBP)                  BANS 005
C                                                                       BANS 010
C   FUNCTION OF SUBROUTINE--TO SOLVE THE MATRIX EQUATION CX = R,        BANS 015
C   RETURNING THE SOLUTION X IN R.  IT IS ASSUMED THAT THE ARRAY        BANS 020
C   C(NP,IB) CONTAINS ONLY THE UPPER HALF BAND OF A SYMMETRIC MATRIX.   BANS 025
C                                                                       BANS 030
C                                                                       BANS 035
      IMPLICIT REAL  (A-H,O-Z)                                            CDC
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP)                                BANS 045
C                                                                       BANS 050
      IHALFB=IHBP-1                                                     BANS 055
      NNP1=NNP-1                                                        BANS 060
C                                                                       BANS 065
C   IF KKK = 1, THEN TRIANGULARIZE THE BAND MATRIX C(NP,IB), BUT        BANS 070
C   IF KKK = 2, THEN SIMPLY SOLVE WITH THE NEW RIGHT-HAND SIDE R(NP)    BANS 075
C                                                                       BANS 080
      IF (KKK.EQ.2) GO TO 50                                            BANS 085
C                                                                       BANS 090
C   TRIANGULARIZE MATRIX C                                              BANS 095
C                                                                       BANS 100
      NU=NNP-IHALFB                                                     BANS 105
      DO 20 NI=1,NU                                                     BANS 110
         NJ=NI-1                                                        BANS 115
         PIVOTI=1./C(NI,1)                                              BANS 120
         DO 20 LB=2,IHBP                                                BANS 125
            A=C(NI,LB)*PIVOTI                                           BANS 130
            NK=NJ+LB                                                    BANS 135
            JB=0                                                        BANS 140
            DO 10 KB=LB,IHBP                                            BANS 145
               JB=JB+1                                                  BANS 150
               C(NK,JB)=C(NK,JB)-A*C(NI,KB)                               CDC
   10       CONTINUE                                                      CDC
            C(NI,LB)=A                                                    CDC
   20    CONTINUE                                                         CDC
      NL=NU+1                                                           BANS 165
      DO 40 NI=NL,NNP1                                                  BANS 170
```

```
         NJ=NI-1                                                        BANS 175
         MB=NNP-NJ                                                      BANS 180
         PIVOTI=1./C(NI,1)                                              BANS 185
         DO 40 LB=2,MB                                                  BANS 190
            A=C(NI,LB)*PIVOTI                                           BANS 195
            NK=NJ+LB                                                    BANS 200
            JB=0                                                        BANS 205
            DO 30 KB=LB,MB                                              BANS 210
               JB=JB+1                                                  BANS 215
               C(NK,JB)=C(NK,JB)-A*C(NI,KB)                               CDC
   30       CONTINUE                                                      CDC
            C(NI,LB)=A                                                    CDC
   40    CONTINUE                                                         CDC
      RETURN                                                            BANS 230
C                                                                       BANS 235
C     MODIFY LOAD VECTOR R                                              BANS 240
C                                                                       BANS 245
   50 NU=NNP-IHALFB                                                     BANS 250
      DO 60 NI=1,NU                                                     BANS 255
         NJ=NI-1                                                        BANS 260
         A=R(NI)                                                        BANS 265
         R(NI)=A/C(NI,1)                                                BANS 270
         DO 60 LB=2,IHBP                                                BANS 275
            NK=NJ+LB                                                    BANS 280
   60       R(NK)=R(NK)-C(NI,LB)*A                                      BANS 285
      NL=NU+1                                                           BANS 290
      DO 70 NI=NL,NNP1                                                  BANS 295
         NJ=NI-1                                                        BANS 300
         MB=NNP-NJ                                                      BANS 305
         A=R(NI)                                                        BANS 310
         R(NI)=A/C(NI,1)                                                BANS 315
         DO 70 LB=2,MB                                                  BANS 320
            NK=NJ+LB                                                    BANS 325
   70       R(NK)=R(NK)-C(NI,LB)*A                                      BANS 330
C                                                                       BANS 335
C     BACK-SOLVE                                                        BANS 340
C                                                                       BANS 345
      R(NNP)=R(NNP)/C(NNP,1)                                            BANS 350
      DO 80 IB=1,IHALFB                                                 BANS 355
         NI=NNP-IB                                                      BANS 360
         NJ=NI-1                                                        BANS 365
         MB=IB+1                                                        BANS 370
         DO 80 KB=2,MB                                                  BANS 375
            NK=NJ+KB                                                    BANS 380
   80       R(NI)=R(NI)-C(NI,KB)*R(NK)                                  BANS 385
      DO 90 IB=IHBP,NNP1                                                BANS 390
         NI=NNP-IB                                                      BANS 395
         NJ=NI-1                                                        BANS 400
         DO 90 KB=2,IHBP                                                BANS 405
            NK=NJ+KB                                                    BANS 410
   90       R(NI)=R(NI)-C(NI,KB)*R(NK)                                  BANS 415
      RETURN                                                            BANS 420
      END                                                               BANS 425
      SUBROUTINE SFLOW(X,Z,TE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,  SFLO 005
     > ISB,NBE,NPB, NPRS,     NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,   SFLO 010
     > MAXBEL,MAXBNP, MXRSNP,        MXSTNP,MAXBCN,KFLOW,DELT,DTH,B,BP, SFLO 015
     > PROP,MAXMAT)                                                       CDC
C                                                                       SFLO 025
C                                                                       SFLO 030
C     FUNCTION OF SUBROUTINE--TO COMPUTE BOUNDARY FLUXES, FLOW RATES,   SFLO 035
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C  INCREMENTAL FLOWS OCCURRING DURING TIME DELT, TOTAL FLOWS SINCE
C  TIME ZERO, AND THE CHANGE IN MOISTURE CONTENT FOR THE ENTIRE
C  SYSTEM DURING TIME DELT.
C
C
      IMPLICIT REAL  (A-H,O-Z)                                        CDC
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION TH(MAXEL,4),VX(MAXNP),VZ(MAXNP)
      DIMENSION DTH(MAXEL,4),H(MAXNP),HP(MAXNP)
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),BFLX(MAXBNP),
     > BFLXP(MAXBNP),NBE(MAXBEL),ISB(MAXBEL,4),NPB(MAXBNP)
      DIMENSION NPRS(MXRSNP),                NPST(MXSTNP),NN(MAXBCN)
      DIMENSION PROP(MAXMAT,5)                                        CDC
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)
C
      DIMENSION XQ(4),ZQ(4),THQ(4)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
C
C
      KKFLOW=0
C
C  CALCULATE NODAL FLOW RATES
C
      DO 10 NP=1,NBN
         BFLXP(NP)=BFLX(NP)
 10      BFLX(NP)=0.
C
      DO 30 MP=1,NBEL
         M=NBE(MP)
         NI=ISB(MP,1)
         NJ=ISB(MP,2)
         DO 20 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NI) GO TO 20
            NII=I
            GO TO 22
 20         CONTINUE
 22      DO 25 J=1,NBN
            IJ=NPB(J)
            IF(IJ.NE.NJ) GO TO 25
            NJJ=J
            GO TO 27
 25         CONTINUE
 27      CONTINUE
C
C  COMPUTE THE FLUX THROUGH POINT NI USING THE WHOLE BOUNDARY LENGTH
C  AND THE FLUX THROUGH POINT NJ USING THE WHOLE BOUNDARY SIDE LENGTH
C
         FNI=(VX(NI)*DCOSXB(MP)+VZ(NI)*DCOSZB(MP))*DLB(MP)
         FNJ=(VX(NJ)*DCOSXB(MP)+VZ(NJ)*DCOSZB(MP))*DLB(MP)
C
C  DISTRIBUTE THE ABOVE FLUXES TO TWO END POINTS OF THE SIDE
C
         BFLX(NII)=BFLX(NII)+FNI/3.0+FNJ/6.0
         BFLX(NJJ)=BFLX(NJJ)+FNJ/3.0+FNI/6.0
C
```

```
   30    CONTINUE
      IF (KFLOW.EQ.0) GO TO 60
      DO 40 NP=1,NBN
   40    HFLXP(NP)=HFLX(NP)
      DO 50 I=1,6
   50    TFLOW(I)=0.
      IF (KFLOW.EQ.(-1)) TFLOW(7)=0.
      IF (KFLOW.EQ.(-1)) QTH=0.
      IF(KFLOW.EQ.(-1)) KKFLOW=-1
      KFLOW=0
C
C  DETERMINE FLOWS AND FLOW RATES THROUGH THE VARIOUS
C  TYPES OF BOUNDARY NODES, STARTING WITH THE
C  NET FLOWS THROUGH ALL BOUNDARY NODES.
C
   60 SUM=0.
      SUMP=0.
      DO 70 NP=1,NBN
         SUM=SUM+HFLX(NP)
   70    SUMP=SUMP+HFLXP(NP)
      FRATE(6)=SUM
      FLOW(6)=.5*(SUM+SUMP)*DELT
C
C  CONSTANT DIRICHLET BOUNDARY NODES
C
      FRATE(1)=0.
      FLOW(1)=0.
      IF (NHC.LE.0) GO TO 90
      SUM=0.
      SUMP=0.
      DO 80 NPP=1,NHC
         NP=NN(NPP)
         DO 75 I=1,NBN
            IJ=NPH(I)
            IF(IJ.NE.NP) GO TO 75
            NII=I
            GO TO 76
   75       CONTINUE
   76    CONTINUE
         SUM=SUM+HFLX(NII)
   80    SUMP=SUMP+HFLXP(NII)
      FRATE(1)=SUM
      FLOW(1)=.5*(SUM+SUMP)*DELT
C
C  CONSTANT NEUMANN BOUNDARY NODES
C
   90 FRATE(2)=0.
      FLOW(2)=0.
      IF (NST.LE.0) GO TO 110
      SUM=0.
      SUMP=0.
      DO 100 NPP=1,NSTN
         NP=NPST(NPP)
         DO 95 I=1,NBN
            IJ=NPH(I)
            IF(IJ.NE.NP) GO TO 95
            NII=I
            GO TO 96
   95       CONTINUE
   96    CONTINUE
```

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```
         SUM=SUM+BFLX(NTI)
  100    SUMP=SUMP+BFLXP(NTI)
      FRATE(2)=SUM
      FLOW(2)=.5*(SUM+SUMP)*DELT
C
C  RAINFALL-SEEPAGE BOUNDARY NODES
C
  110 FRATE(3)=0.
      FLOW(3)=0.
      FRATE(4)=0.
      FLOW(4)=0.
      SUMS=0.
      SUMSP=0.
      SUMR=0.
      SUMRP=0.
      IF (NRSN.LE.0) GO TO 140
      DO 130 NPP=1,NRSN
         NP=NPRS(NPP)
         DO 115 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NP) GO TO 115
            NTI=I
            GO TO 116
  115       CONTINUE
  116    CONTINUE
         BFLXA=.5*(BFLX(NTI)+BFLXP(NTI))
         IF (BFLXA.LT.0.D0) GO TO 120
         SUMS=SUMS+BFLX(NTI)
         SUMSP=SUMSP+BFLXA
         GO TO 130
  120    SUMR=SUMR+BFLX(NTI)
         SUMRP=SUMRP+BFLXA
  130    CONTINUE
      FRATE(3)=SUMS
      FLOW(3)=SUMSP*DELT
      FRATE(4)=SUMR
      FLOW(4)=SUMRP*DELT
C
C  NUMERICAL FLOW THROUGH UNSPECIFIED BOUNDARY NODES
C
  140 SUM=0.
      SUMP=0.
      DO 150 I=1,4
         SUM=SUM+FRATE(I)
  150    SUMP=SUMP+FLOW(I)
      FRATE(5)=FRATE(6)-SUM
      FLOW(5)=FLOW(6)-SUMP
C
C  FINALLY, CALCULATE THE INCREASE IN THE INTEGRATED WATER CONTENT
C
      WTHP=WTH
      WTH=0.
      DO 170 M=1,NEL
         MTYP=IE(M,5)
         ALP=PROP(MTYP,1)
         BETAP=PROP(MTYP,2)
         POR=PROP(MTYP,3)
C
         DO 160 IQ=1,4
            NP=IE(M,IQ)
            XW(IW)=X(NP)                                                    SFLO 940
            ZW(IW)=Z(NP)                                                    SFLO 945
            THW(IW)=TH(M,IW)                                                SFLO 950
            IF(KKFLOW.GE.0) THW(IW)=(DTH(M,IW)+THW(IW)*ALP/POR+BETAP)*      SFLO 955
     >       (H(NP)-HP(NP))                                                 SFLO 960
  160     CONTINUE                                                          SFLO 965
C                                                                           SFLO 970
          CALL W4TH(WTHM,THW,XW,ZW)                                         SFLO 975
C                                                                           SFLO 980
          WTH=WTH+WTHM                                                      SFLO 985
  170     CONTINUE                                                          SFLO 990
        FLOW(7)=WTH                                                         SFLO 995
        IF(KKFLOW.LT.0)  FLOW(7)=0.0                                        SFLO1000
        FRATE(7)=FLOW(7)/DELT                                               SFLO1005
        DO 180 I=1,7                                                        SFLO1010
  180     TFLOW(I)=TFLOW(I)+FLOW(I)                                         SFLO1015
        RETURN                                                              SFLO1020
        END                                                                 SFLO1025
        SUBROUTINE W4TH(WTHM,THW,XW,ZW)                                     W4TH 005
C                                                                           W4TH 010
C  FUNCTION OF SUBROUTINE--TO EVALUATE THE WATER-CONTENT INTEGRAL           W4TH 015
C  OVER THE AREA OF ONE ELEMENT.                                            W4TH 020
C                                                                           W4TH 025
        IMPLICIT REAL   (A-H,O-Z)                                             CDC
        REAL   N(4)                                                           CDC
C                                                                           W4TH 040
        DIMENSION THW(4),S(4),T(4),XW(4),ZW(4)                              W4TH 045
        DIMENSION PJAB(2,2),DNSS(4),DNTT(4)                                 W4TH 050
C                                                                           W4TH 055
        DATA P / 0.577350269189626 /, S / -1.0D+00, 1.0D+00, 1.0D+00,-      W4TH 060
     > 1.0D+00 /, T / -1.0D+00,-1.0D+00, 1.0D+00, 1.0D+00 /                 W4TH 065
C                                                                           W4TH 070
        WTHM=0.                                                             W4TH 075
        DO 20 KG=1,4                                                        W4TH 080
C                                                                           W4TH 085
C  DETERMINE LOCAL COORDINATES (SS,TT) OF GAUSS-INTEGRATION POINT KG        W4TH 090
C                                                                           W4TH 095
          SS = P*S(KG)                                                      W4TH 100
          TT = P*T(KG)                                                      W4TH 105
C                                                                           W4TH 110
C  CALCULATE VALUES OF THE BASIS-INTERPOLATION FUNCTIONS N(IW)              W4TH 115
C                                                                           W4TH 120
          CALL BASE(N,DNSS,DNTT,SS,TT)                                      W4TH 125
C                                                                           W4TH 130
          DO 11 I=1,2                                                       W4TH 135
            DO 11 J=1,2                                                     W4TH 140
   11         PJAB(I,J)=0.0                                                 W4TH 145
          DO 12 I=1,4                                                       W4TH 150
            PJAB(1,1)=PJAB(1,1)+ZW(I)*DNTT(I)                               W4TH 155
            PJAB(1,2)=PJAB(1,2)-ZW(I)*DNSS(I)                               W4TH 160
            PJAB(2,1)=PJAB(2,1)-XW(I)*DNTT(I)                               W4TH 165
   12       PJAB(2,2)=PJAB(2,2)+XW(I)*DNSS(I)                               W4TH 170
          DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)                      W4TH 175
C                                                                           W4TH 180
C  INTERPOLATE TO OBTAIN THE WATER CONTENT THWP AT THE GAUSS POINT KG       W4TH 185
C                                                                           W4TH 190
          THWP=0.                                                           W4TH 195
          DO 10 IW=1,4                                                      W4TH 200
   10       THWP=THWP+THW(IW)*N(IW)                                         W4TH 205
C                                                                           W4TH 210
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C     ACCUMULATE THE SUM TO EVALUATE THE INTEGRAL                       Q4TH 215
C                                                                       Q4TH 220
          QTHM=QTHM+THQP*DJAC                                           Q4TH 225
   20     CONTINUE                                                      Q4TH 230
      RETURN                                                            Q4TH 235
      END                                                               Q4TH 240
      SUBROUTINE PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,PRIN 005
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN, PRIN 010
     > TIME,DELT,SUBHD,IBAND, KPR,KOUT,KDIAG,ITIM)                      PRIN 015
C                                                                       PRIN 020
C                                                                       PRIN 025
C     FUNCTION OF SUBROUTINE--TO OUTPUT FLOWS, PRESSURE HEADS, TOTAL    PRIN 030
C     HEADS, WATER CONTENTS, AND DARCY VELOCITIES AS SPECIFIED BY       PRIN 035
C     PARAMETER KPR.                                                    PRIN 040
C                                                                       PRIN 045
C                                                                       PRIN 050
      IMPLICIT REAL  (A-H,O-Z)                                           CDC
      REAL   SUBHD                                                       CDC
C                                                                       PRIN 065
      DIMENSION VX(MAXNP),VZ(MAXNP),H(MAXNP),HT(MAXNP),TH(MAXEL,4)      PRIN 070
      DIMENSION NPB(MAXBNP),BFLX(MAXBNP),NPRS(MXRSNP),RSFLX(MXRSNP),    PRIN 075
     > NPCON(MXRSNP),NPFLX(MXRSNP)                                      PRIN 080
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)                            PRIN 085
      DIMENSION SUBHD(8)                                                PRIN 090
C                                                                       PRIN 095
C                                                                       PRIN 100
C                                                                       PRIN 105
      IF (KDIAG.NE.0) GO TO 10                                          PRIN 110
      KDIAG=1                                                           PRIN 115
      GO TO 30                                                          PRIN 120
C                                                                       PRIN 125
C     PRINT DIAGNOSTIC FLOW INFORMATION                                 PRIN 130
C                                                                       PRIN 135
   10 KDIAG=KDIAG+1                                                     PRIN 140
      KDIA=KDIAG-1                                                      PRIN 145
      IF(KPR.EQ.0) RETURN                                               PRIN 150
      PRINT 10600,KDIA,TIME,DELT,ITIM,(FRATE(I),FLOW(I),TFLOW(I),I=1,7) PRIN 155
      IF (NRSN.EQ.0) GO TO 30                                           PRIN 160
      DO 20 NPP=1,NRSN                                                  PRIN 165
         NP=NPRS(NPP)                                                   PRIN 170
         DO 15 I=1,NBN                                                  PRIN 175
            IJ=NPB(I)                                                   PRIN 180
            IF(IJ.NE.NP) GO TO 15                                       PRIN 185
            NKK=I                                                       PRIN 190
            GO TO 20                                                    PRIN 195
   15       CONTINUE                                                    PRIN 200
   20    RSFLX(NPP)=BFLX(NKK)                                           PRIN 205
      PRINT 10700                                                       PRIN 210
      PRINT 10100,(RSFLX(NPP),NPP=1,NRSN)                               PRIN 215
      PRINT 10101,(NPCON(NPP),NPP=1,NRSN)                               PRIN 220
      PRINT 10102, (NPFLX(NPP),NPP=1,NRSN)                              PRIN 225
   30 IF (KPR.EQ.1) RETURN                                              PRIN 230
C                                                                       PRIN 235
C     PRINT PRESSURE HEADS                                              PRIN 240
C                                                                       PRIN 245
      KOUT=KOUT+1                                                       PRIN 250
      KLINE=-1                                                          PRIN 255
      PRINT 10200,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)            PRIN 260
      DO 40 NI=1,NNP,8                                                  PRIN 265
         NJMN=NI                                                        PRIN 270
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           NJMX=MIN0(NI+7,NNP)
           KLINE=KLINE+1
           IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10200,KOUT,TIME,
       >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
    40     PRINT 10000,NI,(H(NJ),NJ=NJMN,NJMX)
        IF (KPR.EQ.2) RETURN
C
C   PRINT TOTAL HEADS
C
        KOUT=KOUT+1
        KLINE=-1
        PRINT 10300,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
        DO 50 NI=1,NNP,8
           NJMN=NI
           NJMX=MIN0(NI+7,NNP)
           KLINE=KLINE+1
           IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10300,KOUT,TIME,
       >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
    50     PRINT 10000,NI,(HT(NJ),NJ=NJMN,NJMX)
        IF(KPR.EQ.3) RETURN
C
C   PRINT WATER CONTENTS
C
        KOUT=KOUT+1
        KLINE=-1
        PRINT 10400,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
        DO 60 M=1,NEL,2
           NJMN=M
           NJMX=MIN0(M+1,NEL)
           KLINE=KLINE+1
           IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10400,KOUT,TIME,
       >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
    60     PRINT 10103, (MJ,(TH(MJ,IQ),IQ=1,4),MJ=NJMN,NJMX)
        IF (KPR.EQ.4) RETURN
C
C   PRINT DARCY VELOCITIES
C
        KOUT=KOUT+1
        KLINE=-1
        PRINT 10500,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
        DO 70 NP=1,NNP,4
           KLINE=KLINE+1
           IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10500,KOUT,TIME,
      >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
           NJMN=NP
           NJMX=MIN0(NP+3,NNP)
    70     PRINT 11000, (NJ,VX(NJ),VZ(NJ),NJ=NJMN,NJMX)
        RETURN
C
10000 FORMAT(I7,8(1PE15.4))
10100 FORMAT(1P,8E15.4)
10101 FORMAT(1H0,'VALUES OF NPCON'/(8I15))
10102 FORMAT(1H0,'VALUES OF NPFLX'/(8I15))
10103 FORMAT(1H ,2(1X,I7,2X,1PE12.4,1PE12.4,1PE12.4,1PE12.4,2X,))
10200 FORMAT(13H1OUTPUT TABLE,I4,27H.. PRESSURE HEADS AT TIME =,
      > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(BAND WIDTH =,I4,1H),6H  IT =,
      > I5//1X,8A4/1X,7H NODE I,5X,36HPRESSURE HEAD OF NODES I,I+1,..,I+7
      > /)
10300 FORMAT(13H1OUTPUT TABLE,I4,24H.. TOTAL HEADS AT TIME =, 1PE12.4,
      > 9H ,(DELT =,1PE12.4,15H),(BAND WIDTH =,I4,1H),6H  IT =,I5//1X,8A4
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     > /1X,7H NODE I,5X,33HTOTAL HEAD OF NODES I,I+1,...,I+7/)           PRIN 575
10400 FORMAT(13H1OUTPUT TABLE,I4,27H.. WATER CONTENTS AT TIME =,          PRIN 580
     > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(BAND WIDTH =,I4,1H),6H  IT =,    PRIN 585
     > I5//1X,8A4/30X,5HNODES/2(17X,1H1,11X,1H2,11X,1H3,11X,1H4,6X)/      PRIN 590
     > 2(3X,7HELEMENT,2X,                                                 PRIN 595
     > 46H**********************************************,2X)/)           PRIN 600
10500 FORMAT(13H1OUTPUT TABLE,I4,29H.. DARCY VELOCITIES AT TIME =,        PRIN 605
     > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(BAND WIDTH =,I4,1H),6H  IT =,    PRIN 610
     > I5//1X,8A4/2X,4HNODE,9X,2HVX,9X,2HVZ,4X,4HNODE,9X,2HVX,9X,2HVZ,    PRIN 615
     > 4X,4HNODE,9X,2HVX,9X,2HVZ,4X,4HNODE,9X,2HVX,9X,2HVZ/               PRIN 620
     > 27H***************************,3X,27H***************************,PRIN 625
     >3X,27H***************************,3X,27H***************************PRIN 630
     >*/)                                                                 PRIN 635
10600 FORMAT(1H1,32H TABLE OF SYSTEM-FLOW PARAMETERS,2X,7HTABLE: ,I4,     PRIN 640
     > 12H.. AT TIME =,1PE12.4,9H ,(DELT = 1PE12.4,1H),6H ITIM=,I4//5X,   PRIN 645
     > 13H TYPE OF FLOW,35X,4HRATE,8X,9HINC. FLOW,7X,10HTOTAL FLOW/5X     PRIN 650
     > 40H CONSTANT-PRESSURE-NODE FLOW . . . . . . .,3(F12.4,5X)/5X       PRIN 655
     > 40H CONSTANT-FLUX-NODE FLOW . . . . . . . . .,3(F12.4,5X)/5X       PRIN 660
     > 40H SEEPAGE . . . . . . . . . . . . . . . . .,3(F12.4,5X)/5X       PRIN 665
     > 40H RAINFALL. . . . . . . . . . . . . . . . .,3(F12.4,5X)/5X       PRIN 670
     > 40H NUMERICAL LOSSES. . . . . . . . . . . . .,3(F12.4,5X)/5X       PRIN 675
     > 40H NET FLOW. . . . . . . . . . . . . . . . .,3(F12.4,5X)/5X       PRIN 680
     > 40H INCREASE IN VOLUMETRIC WATER CONTENT. .,3(F12.4,5X))           PRIN 685
10700 FORMAT(/29H RAINFALL-SEEPAGE NODAL FLOWS)                            PRIN 690
11000 FORMAT(1H,1P,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3)       PRIN 695
      END                                                                  PRIN 700
      SUBROUTINE STORE(X,Z,IE,H,HT,TH,VX,VZ,DLB,DCOSXB,DCOSZB,NBE,ISB,    STOR 005
     > NPB,TITLE,TIME,MAXNP,MAXEL,MAXBNP,MAXBEL,NPROB,NNP,NEL,NBN,NBEL,   STOR 010
     > NTI, NPCON,NPFLX,MXRSNP,NRSN, NSTRT)                               STOR 015
C                                                                          STOR 020
C                                                                          STOR 025
C   FUNCTION OF SUBROUTINE--TO STORE PERTINENT QUANTITIES ON AUXILIARY    STOR 030
C   DEVICE FOR FUTURE USE BY EITHER PLOTTING OR MATERIAL-TRANSPORT        STOR 035
C   CODES.  WHAT DEVICE IS TO BE USED MUST BE SPECIFIED BY APPROPRIATE    STOR 040
C   JOB-CONTROL CARDS.                                                    STOR 045
C                                                                          STOR 050
      IMPLICIT REAL  (A-H,O-Z)                                              CDC
C                                                                          STOR 060
      DIMENSION TITLE(9)                                                   STOR 065
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                              STOR 070
      DIMENSION H(MAXNP),HT(MAXNP),VX(MAXNP),VZ(MAXNP),TH(MAXEL,4)         STOR 075
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),     STOR 080
     > ISB(MAXBEL,4),NPB(MAXBNP)                                           STOR 085
      DIMENSION NPCON(MXRSNP),NPFLX(MXRSNP)                                STOR 090
C                                                                          STOR 095
      DATA NPPROB/-1/                                                      STOR 100
C                                                                          STOR 105
      IF (NSTRT.GT.0) GO TO 10                                             STOR 110
      IF (NPPROB.EQ.(-1)) REWIND 1                                         STOR 115
      IF (NPPROB.EQ.NPROB) GO TO 10                                        STOR 120
      WRITE(1) (TITLE(I),I=1,9),NPROB,NNP,NEL,NBN,NBEL,NTI,NRSN            STOR 125
      WRITE(1) (X(NP),NP=1,NNP),(Z(NP),NP=1,NNP),((IE(M,IQ),M=1,NEL),IQ=STOR 130
     >  1,4), (DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),(DCOSZB(M),M=1,       STOR 135
     > NBEL),(NBE(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ=1,4),              STOR 140
     > (NPB(NP),NP=1,NBN)                                                  STOR 145
      NPPROB=NPROB                                                         STOR 150
C                                                                          STOR 155
   10 WRITE(1) TIME,(H(NP),NP=1,NNP),(HT(NP),NP=1,NNP),((TH(M,IQ),M=1,     STOR 160
     > NEL),IQ=1,4),(VX(NP),NP=1,NNP),(VZ(NP),NP=1,NNP),                   STOR 165
     > (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)                         STOR 170
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      RETURN                                                            STOR 175
      END                                                               STOR 180
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This report documents a training course conducted for the U.S. Nuclear Regulatory Commission (NRC) on the implementation of a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. In addition to presenting basic program operation (APPENDIX A-V), the course also covered the following topics: (1) Mathematical equations and physical principles that lead to the code development (APPENDIX A-I), (2) The finite element method (APPENDIX A-II), (3) Finite-element derivation of FEMWATER (APPENDIX A-III), (4) FEMWATER program structure (APPENDIX A-IV), (5) Uniqueness and limitations of FEMWATER (APPENDIX A-VI), and (6) Running of four sample problems (APPENDIX B) to demonstrate various options that FEMWATER can handle. The purpose of the training seminar is to enable the NRC staff to use the model (and to be able to modify the code if necessary) for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results from other methods of solution.

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